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Potential Markets for Plywood Made From Rocky Mountain Ponderosa Pine and Engelmann Spruce

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Potential Markets for Plywood Made From Rocky Mountain Ponderosa Pine and Engelmann Spruce

Final Report

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by

Department of Forest and Wood Sciences
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The Problem

The plywood industry in the Rocky Mountain region has undergone notable expansion in recent years. Between 1952 and 1965 production is estimated to have increased 36 fold and by 1965 installed plant capacity had risen to 1 billion square-feet (3/8-in basis) per year (40). By far the greatest part of this production was in Idaho and Montana. Expansion in other parts of the region --- the Black Hills and the Central and Southern Rockies -- will be largely dependent on the development of markets for ponderosa pine and Engelmann spruce plywood.

Before investigating possible markets for ponderosa pine and Engelmann spruce plywoods, a thorough consideration of the peculiar technical advantages and disadvantages associated with plywood produced from these species must be made in order to establish the market position of this product. A comparison of known mechanical properties of the Rocky Mountain species under consideration with the properties of major plywood species-- Douglas-fir, southern pine and West Coast "whitewoods" -- should bring to light technical advantages and disadvantages and lead one to selecting possible end uses for which ponderosa pine and Engelmann spruce are suited.

The second phase in the development of markets for ponderosa pine and Engelmann spruce plywood is to determine the market acceptance of these plywoods in their potential marketing areas, particularly in the Rocky Mountain and Midwest regions. Analysis of the present use of plywood in these regions, and extrapolation of future uses and the development of new uses for Rocky Mountain plywoods are the key problems in ultimately determining the end uses for which ponderosa pine and Engelmann spruce seem best suited and for which they are likely to command the highest net value (net value equals price of final product less transportation costs from mill to consumer).

Objectives

This investigation into potential markets for Rocky Mountain ponderosa pine and Engelmann spruce plywood was conducted under a research agreement between the Rocky Mountain Forest and Range Experiment Station, U. S. Forest

Service, and the Department of Forest and Wood Sciences at Colorado State University. The overall objectives of the research agreement were to conduct studies and provide reports to establish the following:

A. Technical advantages and disadvantages of ponderosa pine and Engelmann spruce plywood in present Rocky Mountain and Midwest markets when compared to plywood of more established species, such as Douglas-fir, the West Coast "whitewoods," and southern pine.

B. Present and prospective acceptance of ponderosa pine and Engelmann spruce plywood in Rocky Mountain and Midwest markets.

C. Ultimate end uses for which ponderosa pine and Engelmann spruce plywood seem best suited and for which they are likely to command the highest net values.

Following an introductory review of literature, the findings of this study are presented in two parts: Part I dealing primarily with objective A and Part II, dealing with objectives B and C.

Literature Review

Plywood is today an integral part of the world's construction and industrial materials. The Douglas Fir Plywood Association, established in 1938, was expanded during the past decade to include all species of softwood plywood and has changed its name to the American Plywood Association (hereafter referred to as the APA). The industry has matured to the point of adopting industry-wide commercial standards, sponsoring and conducting extensive product research. It has become a major consumer, along with the pulp and paper and lumber industries, of the nation's annual timber harvest. In 1970 consumption of softwood plywood was about 14.2 billion square feet, 3/8-inch basis (39) ---quite a contrast to the 1925 production of Douglas-fir plywood of 0.15 billion square feet (32).

Today a large number of wood species are used in the softwood plywood industry and these species have been classified into five commercial groupings as listed in Table 1.

TABLE 1. CLASSIFICATION OF SOFTWOOD PLYWOOD COMMERCIAL SPECIES*

Group 1	Group 2	Group 3	Group 4	Group 5
Birch	Cedar, Port Orford	Alder, Red	Aspen	Fir, Balsam
Yellow	Douglas Fir 2	Cedar	Bigtooth	Poplar, Balsam
Sweet	Fir	Alaska	Quaking	
Douglas Fir 1	California Red	Pine	Birch, Paper	
Larch, Western	Grand	Jack	Cedar	
Maple, Sugar	Noble	Lodgepole	Incense	
Pine, Caribbean	Pacific Silver	Ponderosa	Western Red	
Pine, Southern	White	Spruce	Fir, Subalpine	
Loblolly	Hemlock, Western	Redwood	Hemlock, Eastern	
Longleaf	Lauan	Spruce	Pine	
Shortleaf	Red	Black	Sugar	
Slash	Tangile	Red	Eastern White	
Tanoak	White	White	Poplar, Western[1]	
	Almon		Spruce, Engelmann	
	Bagtikan			
	Maple, Black			
	Meranti			
	Mengkulang			
	Pine			
	Pond			
	Red		[1]Black Cottonwood	
	Western White			
	Spruce, Sitka			
	Sweet Gum			
	Tamarack			

*Taken from U.S. Product Standard PS 1-66, Softwood Plywood - Construction and Industrial (28).

The grouping assignments are based on mechanical properties at the clear wood level using the criteria of the American Society for Testing and Materials (ASTM) Standard D2555 - "Standards for Establishing Clear Wood Strength Values"(11). In classifying new species the industry follows the practice of giving the new species the best group assignment its clear wood properties will allow as long as the design values presently assigned to the group are not reduced (9).

A review of pertinent literature was begun with an examination of the problems encountered in the development of the southern pine plywood industry in the late 1950's and early 1960's (the industry's development years with the first operational plant established in December, 1963). It is to be expected that many of the product development and marketing problems faced by Southern developers can also be anticipated in the Rocky Mountain region. Additional difficulties caused by the different physical and mechanical properties of the Rocky Mountain species may also be found.

Feasibility studies on the use of southern pines in the production of plywood were done as early as 1945 by the F.P.L. but even with this lengthy research background production difficulties were many and varied(20). Promoting a new wood product is especially difficult because of the need to reach particular markets with specialty items, meet building code specifications and inspections, and create an efficient distribution system (33). The building materials market is traditionally conservative, therefore a new product means some radical changes in marketing policy. The first persons who must be convinced of the advantages of a new product are the architects and engineers. Even after these key people are aware of a new product, there continues to be a lag in its acceptance by users. The promotion problem becomes one of reaching a highly restricted market (33) and bucking the established products (20).

A major point in considering a new product is to allow sufficient lead time to get approval by the Federal Housing Authority, Major National Codes, and Key Local Codes (33).

It was discovered early in the development of the southern pine plywood industry that mills, in order to be competitive, must be of the high volume, mass production type geared to turn out quality plywood in volume at a low unit cost. An integrated operation was found to be almost essential for good management of resources (22,29). These points are worthy of consideration for potential Rocky Mountain developers although beyond the scope of this project.

A factor that figured significantly in the ultimate success of the southern pine plywood industry was the cooperation afforded southern pine producers by the already well-established Pacific Northwest industry (17).

The first market to be attacked by Southern producers was the Southern market which in 1963-64 comprised 17-19% of total national volume (16). This market strategy, although very basic and logical, is a significant item for consideration. This approach coupled with the geographic fact that approximately 70% of the total plywood market is east of the 100th meridian (21) has contributed to the growing success of southern pine plywood(24).

The above thoughts and factors although discussed in light of southern pine plywood production are applicable to this situation. Advance consideration of these factors by potential Rocky Mountain plywood producers could avoid many possible problems.

The volume of literature dealing with plywood production in the Rocky Mountains is much less than that of the southern pine region or the Pacific Northwest. The majority of the Rocky Mountain related literature deals with the marketing potential of ponderosa pine and Engelmann spruce plywoods and the problems inherent in establishing manufacturing facilities.

It is estimated that the U. S. market for softwood plywoods will be 18.5 billion square feet by 1975 on a 3/8" basis (3). To help meet this increasing demand the states of Arizona, New Mexico, Colorado, Wyoming and South Dakota had a small number of plywood plants in various stages of consideration and one in operation as of 1966 (15). However, as of 1971, there is still only one plant in operation.

Some of the changes necessary in the Rocky Mountain forest products industry before there can be extensive plywood manufacture include changes in logging methods, acceptance of mixed species plywoods, a pool of skilled personnel, and possible changes in grouping classifications of certain plywood species (15). Changes considered relevant to this study are the acceptance of mixed species plywood and possible changes in grouping classification of certain plywood species as established by Product Standard 1-66. Two species of particular importance to the Rocky Mountain region are ponderosa pine and Engelmann spruce. Recent studies at Colorado State University indicate that on the basis of MOE (1,200,000 psi) Engelmann spruce qualifies for a rating of Group 3 (35). If this reassignment of Engelmann spruce were accepted, a 5/8" panel could be identified as suitable for 32" spans as roof sheathing bringing Engelmann spruce into line with other Group 3 species such as ponderosa pine.

In order to analyze the market for ponderosa pine and Engelmann spruce plywood we must first be aware of the current plywood market situation. From 1968 production data there were 14,700 million square feet of softwood plywood produced in the United States (26). Based on 1965 data nearly 77% of this plywood was made in the Columbia-Willamette and Oregon-California regions. About 71% of this was interior plywood. The six market areas east of the Great Plains received 66% of the plywood produced. The Columbia-Willamette and Oregon-California regions produced over 60% of the softwood plywood sold in each of the ten market areas. The southern pine plywood industry markets nearly all of its plywood in the Southeastern area. The Southern industry makes nearly all interior plywood (45).

A contention probably widely held is that ponderosa pine and Engelmann spruce plywood will not be able to capture many of the markets currently held by the West Coast plants. This is probably true when one considers competing with West Coast plants on their home ground but not for areas close to potential Rocky Mountain producers. According to Barger and Fleischer in a 1964 Forest Service research paper, an ideal place for this type of plywood is in floor underlayment (14). There is not a great deal of strength required and sheets with sound knots or patches can be used for

this purpose, but ponderosa pine and Engelmann spruce plywoods are by no means limited to floor underlayment.

Based on 1965 plywood consumption figures developed by grouping Rand McNally Major Trading Areas, it is estimated that the Rocky Mountain area consumes only 5% of the softwood plywood. The North Central area consumed 8% (45). Combined, these areas of potential exploitation by Rocky Mountain producers offer an opportunity to capture an estimated 13% of the total softwood plywood market.

With this potential "local" market as a base for competition in standard plywood products, market and product opportunities for specialty items produced from plywood of these species may be expected to further expand the sales of these plywoods on a nationwide basis.

Part I. TECHNICAL ADVANTAGES AND DISADVANTAGES

According to the U.S. Product Standard PS 1-66 (28) commercial species groupings, ponderosa pine is classified as a Group 3 species and Engelmann spruce as a Group 4 species. A summary of the stiffness and strength values assigned to the various commercial plywood groupings is presented below as Table 2.

Based upon allowable stresses and other mechanical property data in Table 2, plywood use tables such as are found in various publications of the American Plywood Association have been prepared for a number of important commercial plywood uses. Through the use of these tables the authors will suggest favorable and unfavorable applications (from the technical standpoint) of ponderosa pine and Engelmann spruce plywoods.

Stiffness and Strength Comparisons for Major Plywood Uses

Roof and Floor Sheathing

Due to the large volume of plywood used as sheathing, the requirements of this product were investigated first. Standard, Structural I and II, and C-C Exterior sheathing grade plywoods produced under Product Standard PS 1-66 are marked with an Identification Index. This Identification Index (Figure 1) serves as an indicator of the allowable roofing and flooring spans for which a particular plywood panel is mechanically suited, regardless of species.

In Figure 1 the 48 stands for use as roof sheathing with maximum support spacing, center to center, of 48 inches; and the 24 stands for use in sub-flooring with a maximum support spacing, center to center, of 24 inches.

TABLE 2. ALLOWABLE STRESSES FOR PLYWOOD [From APA Plywood Design Specification (4)]

Conforming to U. S. Product Standard PS 1, for Softwood Plywood, Construction and Industrial

Normal Load Basis, psi

To be used with section properties in Section 2.10

Dry Location

Type of Stress	Species Group	EXTERIOR A-A, A-C, C-C[1], and comparable grades of Overlaid plywood. STRUCTURAL I A-A, STRUCTURAL I A-C, STRUCTURAL I C-C, and Marine (Use Group 1 stresses)	EXTERIOR A-B, B-B, B-C C-C (Plugged). Plyform Class I[1] Plyform Class II[1] and comparable grades of Overlaid plywood. STRUCTURAL I C-D (Use Group 1 stresses). STRUCTURAL II C-D STANDARD SHEATHING (Exterior Glue)[1] ALL INTERIOR GRADES WITH EXTERIOR GLUE	All other grades of Interior including STANDARD SHEATHING[1]
Extreme fiber in bending, Tension Face grain parallel or perpendicular to span (at 45° to face grain use 1/6)	1 2, 3 4	2,000 1,400 1,200	1,650 1,200 1,000	1,650 1,200 1,000
Compression Parallel or perpendicular to face grain (at 45° to face grain use 1/3)	1 2, 3 4	1,650 1,200 1,000	1,550 1,100 950	1,550 1,100 950
Bearing (on face)	1 2, 3 4	340 220 160	340 220 160	340 220 160
Shear in plane perpendicular to plys[2] Parallel or perpendicular to face grain (at 45° increase 100%)	1 2, 3 4	250 185 175	250 185 175	230 170 160
Shear, rolling, in plane of plys[3] Parallel or perpendicular to face grain (at 45° increase 1/3)	All	53	53	48
Modulus of Elasticity in bending Face grain parallel or perpendicular to span	1 2 3 4	1,800,000 1,500,000 1,200,000 900,000		

(1) Exterior C-C, Structural II and Standard Sheathing: The combination of Identification-Index designation and panel thickness determine the minimum species group and, therefore, the stress permitted, as follows:

5/16 - 20/0, 3/8 - 24/0, 1/2 - 32/16, 5/8 - 42/20, 3/4 - 48/24 – Use Group 2 working stresses.

All other combinations of C-C and Standard – Use Group 4 working stresses. Other combinations of Structural II – Use Group 3 working stresses.

For Plyform Class I – Use Group 1 stresses. For Plyform Class II – Use Group 3 stresses.

For 2-4-1 – Use Group 1 stresses.

(2) Shear-through-the-thickness stresses are based on the most common structural applications where the plywood is attached to framing around its boundary. Where the plywood is attached to framing at only two sides – as in the heel joint of a truss – multiply the allowable shear-through-the-thickness values by 89% where framing is parallel to face grain and 75% where it is perpendicular.

(3) For Marine and STRUC I grades use 75 psi. For STRUC II use 56 psi.

Wet or Damp Location

Where moisture content is 16% or more, multiply the dry location values by the following factors:

For all grades of Exterior and Interior plywood with exterior glue,

Extreme fiber in bending – 75%	Modulus of Elasticity – 89%
Tension – 69%	Shear – 84%
Compression – 61%	Bearing – 67%

For all other grades of Interior,

Extreme fiber in bending – 69%	Modulus of Elasticity – 80%
Tension – 69%	Shear – 84%
Compression – 61%	Bearing – 67%

STANDARD

48/24

INTERIOR

PS 1-66 000

TESTED

DFPA

QUALITY

FIGURE 1. Example of an American Plywood Association Identification Index

The Identification Index assigned to a panel of a particular construction is a function of the species used for the face and back plys and the overall thickness of the finished panel.

Correspondence with the American Plywood Association has provided information presented in Table 3 that delineates the relationship between stiffness and strength and Identification Indexes.

Based on the information in Table 3, Table 4 was prepared to relate Identification Indexes and minimum EI and fKS values with commercial species groupings in general and with Engelmann spruce and ponderosa pine in particular. EI is the product of the Modulus of Elasticity (E) and Moment of Inertia (I) of a plywood section. The term fKS is used to refer to the product of the extreme fiber in bending (f or f_b, which are used interchangeably in this report) and the effective section modulus (KS) of a plywood construction.

In Table 4 and several other tables to follow, a wide variety of plywood constructions were evaluated, ranging from a panel composed entirely of Douglas-fir---a Group 1 species---to panels made entirely of Engelmann spruce---a Group 4 species. These various constructions are compared in Table 5.

Values assigned to the Modulus of Elasticity (MOE) and Extreme Fiber in Bending (f_b) for the various plywood constructions are based on the following six sources; the American Plywood Association's Plywood Design Specification, April, 1969, Table 3.14; The Wood Handbook, U.S.D.A. Handbook #72, Table 12; ASTM Standard D2555, Establishing Clear Wood Strength Values; ASTM Standard D245, Tentative Methods for Establishing Structural Grades of Lumber; Forest Products Laboratory Research Paper 128, January, 1970, Mechanical Properties and Specific Gravity

TABLE 3. MINIMUM EI AND fKS RECOMMENDED FOR IDENTIFICATION INDEXES*

IDENTIFICATION INDEX	MINIMUM EI	MINIMUM fKS
20/0	46,800	223
24/0	84,600	293
30/12	157,900	---
32/16	172,500	442
36/16	239,600	---
42/20	300,600	678
48/24	469,800	864

*Enclosure in personal letter from American Plywood Association to F.F. Wangaard (7).

of a Randomly Selected Sampling of Engelmann Spruce; and the results of independent unpublished research conducted at Colorado State University.

The strength and stiffness values for plywood constructions 1, 2, 3, 4, and 6 were taken directly from Table 3.14 of the APA Plywood Design Specification. The values for plywood constructions 5, 7, and 8 were derived in the following manner:

Construction 5 - All plys ponderosa pine (E = 1,230,000 psi and f_b = 1130 psi)

In Table 2 of ASTM Standard D2555, ponderosa pine is assigned a green clear wood MOE of 997,000 psi. Table A-1 of the same Standard lists a 1.30 drying increase factor for ponderosa pine MOE (9). In calculating design MOE for a combination of species the APA applies a 5 percent reduction due to grade. Since the MOE assigned a combination is the weighted average value for all species included in the combination and no 5 percent exclusion limit is calculated for this property as outlined in ASTM Standard D2555, no attempt was made here to allow for variation in ponderosa pine. Based on the above considerations, a theoretical dry design MOE for ponderosa pine is calculated in the following manner:

Green Clear Wood MOE	X	Drying Factor	X	Grade Reduction Factor	=	Design MOE
997,000 psi	X	1.30	X	.95	=	1,230,000 psi

An extreme fiber in bending strength of 1130 psi was calculated using the criteria established for determining strength values for combinations of species in ASTM Standard D2555. Based on an average green Modulus of Rupture (MOR) for ponderosa pine of 5130 psi and a standard deviation of 821 psi, the 5 percent exclusion limit (EL) MOR is 3780 psi assuming a sample size greater than 120. To arrive

at a design value for extreme fiber in bending, the same reduction factor used by the APA for combinations of species was used. This reduction factor is .2084 and includes reductions for normal loading, veneer grade (C-D veneer used), variations in panel thickness, and other manufacturing variables.

Therefore, f_b is calculated in the following manner:

f_b = MOR (5% EL) X Drying Factor X Reduction Factor

f_b = 3780 psi X 1.44 X .2084 = 1134 $\approx$ 1130

Construction 7 - All plys Engelmann spruce (E = 1,380,000 psi and f_b = 2740 psi, Exterior Glue Line).

Five-ply, parallel laminated Engelmann spruce panels were manufactured and tested at the Colorado State University Wood Science Laboratory by Schuldt and Troxell (34). Static-bending tests conducted at CSU on 5-ply, parallel laminated C-D veneer made from timber from the San Juan National Forest in Colorado and donated by Montezuma Plywood Company, assigned an average MOE of 1,340,000 psi and an average specific gravity of .399 including the weight of the exterior adhesive. Subtracting the weight of the adhesive, the specific gravity for the exterior-bonded veneers was .360. The uncompressed average specific gravity of the San Juan Engelmann spruce C-D veneer was .34 based on oven-dry weight and volume at 12 percent moisture content as determined by Schuldt (34). The higher specific gravity of the laminated test material is attributed to densification due to the pressures of the normal manufacturing press cycle for exterior adhesives. When adjusted to an uncompressed

veneer specific gravity of .354, which is the projected average whole tree specific gravity for Engelmann spruce grown in Colorado and Wyoming as reported by Troxell and Wangaard (35), the panels bonded with exterior adhesives have a calculated modulus of elasticity of 1,380,000 psi. The specific gravity conversion is calculated using the following formula (37):

$$P_c = P\left(\frac{SG}{SG_1}\right)^N$$

Where: P_c = Corrected property (MOR or MOE)
P = Uncorrected property (MOR or MOE)
SG_1 = Specific gravity of laminate panel
SG = Average specific gravity of Colorado and Wyoming Engelmann spruce
N = Exponent (1.5 for MOR and 1.25 for MOE)

The numerical value of $\left(\frac{SG}{SG_1}\right)^N$ is the specific gravity conversion factor referred to in the calculations below. Therefore, E is calculated in the following manner:

$$P_c = 1{,}340{,}000\left(\frac{.354}{.34}\right)^{1.25} = 1{,}380{,}000 \text{ psi}$$

Also from the tests conducted by Schuldt on 5-ply, parallel laminated Engelmann spruce veneer bonded with exterior adhesive come data on the MOR of this species. It was found that the average MOR of the sample, with exterior glue, was 8175 psi with a standard deviation of 706 psi. Calculating the 5 percent EL for MOR based on a sample size of 27 panels gives a value of 6974 psi.

To this 5 percent exclusion limit MOR value were applied the factors normally used by the APA for a ten-year-duration load, an accidental overload, and a specific gravity conversion to .354 for Colorado and Wyoming Engelmann spruce.

$$f_b = \text{5\% EL MOR} \times \begin{matrix}\text{Specific Gravity} \\ \text{Conversion Factor}\end{matrix} \times \begin{matrix}\text{10-Year Duration} \\ \text{of Load Factor}\end{matrix} \times \begin{matrix}\text{Accidental} \\ \text{Overload Factor}\end{matrix}$$

$$f_b = 6974 \text{ psi} \times 1.056 \times (.563 \times 1.1) \times .6 = 2737 \text{ psi} \approx 2740 \text{ psi}$$

This is a surprisingly high value, almost twice as high as is normally assumed for this species. The APA uses a reduction factor of approximately .56 for all species to account for C-D grade veneer and variations in panel thickness. Since the test material used was C-D veneer, the test values already include the grade reduction factor. An f_b of 2740 psi seems to suggest that the usual grade reduction factor may be too severe for Engelmann spruce plywood.

Construction 8 - All plys Engelmann spruce (E = 1,240,000 psi and f_b = 2400 psi, Interior Glue Line)

These values were also developed from research at this University based on spruce from the San Juan National Forest. The average test value MOE is 1,240,000 psi adjusted to a specific gravity of .354 for spruce from Colorado and Wyoming. Also in the manufacture of interior panels, a densification of the veneer occurred but to a lesser degree than in the exterior

panels. The reason the exterior panels exhibited a higher specific gravity and also a higher MOE is probably attributable to the increase in density caused by a more severe press cycle associated with exterior adhesive bonding.

The extreme fiber in bending was calculated in the same manner as that used for Construction 7 using a sample size of 42 panels.

$$f_b = \text{5\% EL MOR} \times \text{SG Adjustment} \times \frac{\text{10-Year Loading}}{\text{Reduction}} \times \frac{\text{Accidental}}{\text{Overload}}$$

$$f_b = [7580 - (866 \times 1.684)] \times 1.056 \times (.563 \times 1.1) \times .6 = 2402 \text{ psi} \approx 2400 \text{ psi}$$

From the minimum EI and fKS required for a particular Identification Index (Table 3) and the assigned and calculated MOE and f_b of a particular plywood construction (Table 5), the following procedure was used to develop the panel thickness and number of plys required for various construction and panel indexes (Table 4).

Sample calculations for assigned values in Table 4 for Identification Index 24/0 are presented below for the reader's clarification:

IDENTIFICATION INDEX	MINIMUM EI	MINIMUM fKS
24/0	84,600 lb.in.^{2}	293 lb.in.

CONSTRUCTION (from Table 5)	MOE (psi)	f_b (psi)
1. All plys Group 1	1,800,000	1650
2. Face and back Group 1, inner plys any plywood species	1,800,000	1650

TABLE 4. COMPARISON OF PANEL CONSTRUCTIONS REQUIRED TO MEET IDENTIFICATION INDEX STANDARDS.

IDENT. INDEX	MINIMUM		PANEL DESCRIPTION			MINIMUM		THICKNESS REQUIRED		THICKNESS TO MEET BOTH CRITERIA	# OF PLYS
	EI	fKS	1/ GROUP	EX10^6	f	I	KS	I	KS		
20/0	46800	223	1 APA	1.80	1650	.026	.135	5/16	5/16	5/16	3
			1 APA	1.80	1650	.026	.135	5/16	5/16	5/16	3
			2 APA	1.50	1200	.031	.186	3/8	3/8	3/8	3
			3 APA	1.20	1200	.039	.186	3/8	3/8	3/8	3
			PP ASTM	1.23	1130	.038	.197	3/8	3/8	3/8	3
			4 APA	.90	1000	.052	.223	3/8	3/8	3/8	3
			ES EXT	1.38	2740	.034	.082	3/8	5/16	3/8	3
			ES INT	1.24	2400	.038	.093	3/8	5/16	3/8	3
24/0	84600	293	1 APA	1.80	1650	.047	.178	3/8	3/8	3/8	3
			1 APA	1.80	1650	.047	.178	3/8	3/8	3/8	3
			2 APA	1.50	1200	.056	.244	1/2	1/2	1/2	3 or 5
			3 APA	1.20	1200	.071	.244	1/2	1/2	1/2	3 or 5
			PP ASTM	1.23	1130	.069	.259	1/2	1/2	1/2	3 or 5
			4 APA	.90	1000	.094	.293	1/2	1/2	1/2	3 or 5
			ES EXT	1.38	2740	.061	.107	1/2	5/16	1/2	3 or 5
			ES INT	1.24	2400	.068	.122	1/2	5/16	1/2	3 or 5
30/12	157900		1 APA	1.80	*	.088	*	1/2	*	1/2	3 or 5
			1 APA	1.80		.088		1/2		1/2	3 or 5
			2 APA	1.50		.105		5/8		5/8	5
			3 APA	1.20		.132		5/8		5/8	5
			PP ASTM	1.23		.128		5/8		5/8	5
			4 APA	.90		.175		5/8		5/8	5
			ES EXT	1.38		.114		5/8		5/8	5
			ES INT	1.24		.127		5/8		5/8	5
32/16	172500	442	1 APA	1.80	1650	.096	.268	1/2	1/2	1/2	3 or 5
			1 APA	1.80	1650	.096	.268	1/2	1/2	1/2	3 or 5
			2 APA	1.50	1200	.115	.368	5/8	5/8	5/8	5
			3 APA	1.20	1200	.144	.368	5/8	5/8	5/8	5
			PP ASTM	1.23	1130	.140	.391	5/8	5/8	5/8	5
			4 APA	.90	1000	.192	.442	3/4	5/8	3/4	5
			ES EXT	1.38	2740	.125	.162	5/8	3/8	5/8	5
			ES INT	1.24	2400	.139	.184	3/4	3/8	3/4	5
36/16	239600		1 APA	1.80	*	.133	*	5/8	*	5/8	5
			1 APA	1.80		.133		5/8		5/8	5
			2 APA	1.50		.160		5/8		5/8	5
			3 APA	1.20		.200		3/4		3/4	5
			PP ASTM	1.23		.195		3/4		3/4	5
			4 APA	.90		.266		3/4		3/4	5
			ES EXT	1.38		.174		5/8		5/8	5
			ES INT	1.24		.193		3/4		3/4	5

TABLE 4. COMPARISON OF PANEL CONSTRUCTIONS REQUIRED TO MEET IDENTIFICATION INDEX STANDARDS (Cont.)

IDENT. INDEX	MINIMUM		PANEL DESCRIPTION			MINIMUM		THICKNESS REQUIRED		THICKNESS TO MEET BOTH CRITERIA	# OF PLYS
	EI	fKS	1/ GROUP	$EX10^6$	f	I	KS	I	KS		
42/20	300200	678	1 APA	1.80	1650	.167	.411	5/8	5/8	5/8	5
			1 APA	1.80	1650	.167	.411	5/8	5/8	5/8	5
			2 APA	1.50	1200	.200	.565	3/4	3/4	3/4	5
			3 APA	1.20	1200	.250	.565	3/4	3/4	3/4	5
			PP ASTM	1.23	1130	.244	.600	3/4	3/4	3/4	5
			4 APA	.90	1000	.334	.678	7/8	7/8	7/8	7
			ES EXT	1.38	2740	.218	.248	3/4	1/2	3/4	5
			ES INT	1.24	2400	.242	.282	3/4	1/2	3/4	5
48/24	469600	864	1 APA	1.80	1650	.261	.524	3/4	3/4	3/4	5
			1 APA	1.80	1650	.261	.524	3/4	3/4	3/4	5
			2 APA	1.50	1200	.313	.720	13/16	7/8	7/8	7
			3 APA	1.20	1200	.391	.720	7/8	7/8	7/8	7
			PP ASTM	1.23	1130	.382	.765	7/8	7/8	7/8	7
			4 APA	.90	1000	.523	.864	1	7/8	1	7
			ES EXT	1.38	2740	.340	.316	7/8	1/2	7/8	7
			ES INT	1.24	2400	.379	.360	7/8	5/8	7/8	7

1/ See Table 5 for group or species descriptions, 1-8 in order from top to bottom of this column.

* Minimum KS values not available for this span index.

TABLE 5. COMPARATIVE PLYWOOD CONSTRUCTIONS AND PROPERTIES (C-D GRADES)

	PLYWOOD DESCRIPTION	MOE	f_b	SOURCE OF DATA
1.	All plys Group 1	1,800,000	1650	APA Design Specification
2.	Face and back Group 1 core any plywood species	1,800,000	1650	" " "
3.	All plys Group 2	1,500,000	1200	" " "
4.	All plys Group 3	1,200,000	1200	" " "
5.	All plys ponderosa pine	1,230,000	1130	Wood Handbook and ASTM D2555
6.	All plys Group 4	900,000	1000	APA Design Specification
7.	All plys Engelmann spruce w. ext. glue	1,380,000	2740	Colorado State University Tests
8.	All plys Engelmann spruce w. int. glue	1,240,000	2400	Colorado State University Tests

CALCULATIONS

Construction 1

$$I_{min} = \frac{\text{Min EI}}{E} = \frac{84{,}600 \text{ lb.in.}^2 \text{ per 12 in. width}}{1{,}800{,}000 \text{ psi}} = .047 \text{ in.}^4$$

$$KS_{min} = \frac{\text{Min fKS}}{f} = \frac{293 \text{ lb.in. per 12 in. width}}{1650 \text{ psi}} = .178 \text{ in.}^3$$

Construction 2

$$I_{min} = \frac{\text{Min EI}}{E} = \frac{84{,}600 \text{ lb.in.}^2 \text{ per 12 in. width}}{1{,}800{,}000 \text{ psi}} = .047 \text{ in.}^4$$

$$KS_{min} = \frac{\text{Min fKS}}{f} = \frac{293 \text{ lb.in. per 12 in. width}}{1650 \text{ psi}} = .178 \text{ in.}^3$$

The columns in Table 4 headed "Thickness Required---I and KS"--- were developed directly by referring to the APA Plywood Design Specification (4), Tables 2.10.1 and 2.10.2, Effective Section Properties for Plywood (12-inch widths) - Face Plys of Different Species Group from Inner Plys and All Plys from Same Species Group. Referring to the above example it can be seen that Construction 1 is one in which the face and back plys are of the same species as the inner plys; therefore, it is necessary to use the referenced Table 2.10.2. This table shows that to satisfy a minimum EI of 84,600 lb.in.^{2} per 12-inch width, using a panel composed entirely of a Group 1 species, a 3/8-inch thick unsanded panel is required. Likewise, to satisfy a minimum fKS of 293 lb.in. per 12-inch width would also require a 3/8-inch thick unsanded panel. For panel Construction 2, APA Table 2.10.1 must be used because in this construction the face plys are of a different species than the inner plys. Construction 2 is the only one that uses APA Table 2.10.1 and throughout the range of Identification Indexes the same thickness is always required but the reader should be aware of the applicability of the two referenced APA tables when considering various plywood constructions.

The thickness required to meet both stiffness and strength criteria is determined in all cases. The thicker of the two dimensions becomes the required panel thickness. From this required thickness the number of plys in that construction can be determined by referring again to the APA Plywood Design Specification and Table A2.2.1, Plywood Panel Construction Used in Calculating Section Properties. In the examples given, a 3/8-inch rough panel is normally of three-ply construction.

By using Table 4 of this report, the reader should be able to make several key comparisons; the first of these being a comparison of thicknesses and groups for the various indexes. In the following discussion, Constructions 1, 2, 3, 4, and 6 were chosen because all strength and stiffness values for these constructions were accepted values taken from APA published tables. Therefore, using these constructions and working strictly within the present ground rules of Product Standard 1-66 and the American Plywood Association established criteria, one can make comparisons between Douglas-fir, the West Coast "whitewoods", southern yellow pines, and the study species---ponderosa pine and Engelmann spruce---that fall within current marketing constraints.

IDENTIFICATION INDEX 20/0

Referring to Table 4 for this particular index it can be seen that a ponderosa pine panel or an Engelmann spruce panel can have the same index and do the same job as a panel of all Group 2 plys of the same thickness.

IDENTIFICATION INDEX 24/0

Once again, the study species can compete favorably with an all Group 2 panel.

IDENTIFICATION INDEX 30/12

Same as above.

IDENTIFICATION INDEX 32/16

In this case only ponderosa pine can compete with an all Group 2 panel.

IDENTIFICATION INDEX 36/16

In this case neither ponderosa pine nor Engelmann spruce can compete with Group 2 but a spruce panel can do the same job as a ponderosa pine panel or any other panel of all Group 3 plys.

IDENTIFICATION INDEX 42/20

Once again this is a case where ponderosa pine can compete with an all Group 2 panel but an Engelmann spruce panel cannot.

IDENTIFICATION INDEX 48/24

Same as 42/20.

In view of the imminent possibility that Engelmann spruce may be granted Group 3 status by APA, any reference in the foregoing to ponderosa pine would in that case apply equally to Engelmann spruce.

Another comparison that can be made is between Engelmann spruce, Constructions 7 and 8, and Constructions 1, 2, 3, 4, and 6. As noted before, the values assigned to Constructions 7 and 8 come from the results of independent tests conducted at CSU (34) using 5-ply, parallel laminated C and D spruce panels.

IDENTIFICATION INDEXES 20/0, 24/0, 30/12, 42/20, and 48/24

These particular indexes allow a spruce panel bonded with either exterior or interior adhesives to be the same thickness as panels of all Group 3 or Group 2 plys.

IDENTIFICATION INDEX 32/16

In this case an exterior bonded spruce panel can have the same index and be the same thickness as a Group 2 or 3 panel but an interior bonded panel must be thicker to carry the same index rating.

IDENTIFICATION INDEX 36/16

For this construction an exterior bonded spruce panel can have the

same index and be the same thickness as a panel made entirely of Group 1 plys. Whereas the interior spruce panel can only equal a Group 3 panel in thickness required.

For all indexes it is worthwhile to note that the thickness required for Constructions 7 and 8 is no greater than that required for Construction 4 (panel of all Group 3 plys) and in some cases it is less. At this point it is necessary to again point out that the modulus of elasticity and the extreme fiber in bending assigned to Constructions 7 and 8 are new values established by recent tests at CSU (34) and are not approved values within the standards of the APA or PS 1-66. However, it is felt that these values are useful in predicting the actual stiffness and strength potentials of C-D Engelmann spruce plywood of all thicknesses.

The final comparison to be made from Table 4 is that between ponderosa pine Construction 5 and Constructions 1, 2, 3, 4, and 6. As noted before, the values assigned to Construction 5 were developed by applying the criteria of ASTM Standard D2555 and the APA.

IDENTIFICATION INDEXES 20/0, 24/0, 30/12, 32/16, 36/16, 42/20, and 48/24

For these indexes, Construction 5 would be permitted to be of the same thickness as a Group 2 panel.

Again it should be stressed that the values for MOE and extreme fiber in bending assigned to Construction 5 are not approved values within the standards of the APA or PS 1-66. However, they are based on APA criteria and therefore should be an acceptable representation of the performance of C-D ponderosa pine plywood when removed from the Group 3 species mix.

Tables 6 and 7 allow the reader to make plywood species comparisons based on allowable roof and floor loads in pounds per square foot, rather

TABLE 6. SPAN TABLE FOR PLYWOOD ROOF DECKING--STANDARD SHEATHING GRADE

Thickness	Const.#	Plywood Description	Allowable Roof Loads (psf) - Spacing of Supports, Center to Center				
			12	16	24	32	48
	1.	Group 1	200*	111	31		
	2.	Group 1 face,back	200*	111	31		
	3.	Group 2	200*	93	26		
	4.	Group 3	167	74	21		
5/16	5.	Ponderosa pine	171	76	21		
	6.	Group 4	125	56	16		
	7.	E. spruce (ext.)	192	85	24		
	8.	E. spruce (int.)	173	76	22		
	1.	Group 1	421**	205	58		
	2.	Group 1 face, back	421**	201	57		
	3.	Group 2	306**	171	48		
	4.	Group 3	306**	137	39		
3/8	5.	Ponderosa pine	316	140	40		
	6.	Group 4	211	93	26		
	7.	E. spruce (ext.)	354	157	44		
	8.	E. spruce (int.)	319	141	40		
	1.	Group 1		372**	120	51	
	2.	Group 1 face, back		372**	119	51	
	3.	Group 2		271**	100	43	
	4.	Group 3		271**	80	34	
1/2	5.	Ponderosa pine		279	82	35	
	6.	Group 4		204	60	26	
	7.	E. spruce (ext.)		313	92	39	
	8.	E. spruce (int.)		281	83	35	
	1.	Group 1			211	88	
	2.	Group 1 face, back			206	86	
	3.	Group 2			170**	73	
	4.	Group 3			141	54	
5/8	5.	Ponderosa pine			144	58	
	6.	Group 4			105	44	
	7.	E. spruce (ext.)			161	67	
	8.	E. spruce (int.)			145	61	
	1.	Group 1			295**	136	39
	2.	Group 1 face, back			285**	133	38
	3.	Group 2			214**	114	33
	4.	Group 3			214	91	26
3/4	5.	Ponderosa pine			219	93	27
	6.	Group 4			160	68	20
	7.	E. spruce (ext.)			246	105	30
	8.	E. spruce (int.)			221	94	27
	1.	Group 1				238	69
	2.	Group 1 face, back				210	61
	3.	Group 2				187**	57
	4.	Group 3				159	46
7/8	5.	Ponderosa pine				163	47
	6.	Group 4				119	34
	7.	E. spruce (ext.)				182	53
	8.	E. spruce (int.)				164	47

TABLE 6. SPAN TABLE FOR PLYWOOD ROOF DECKING (Cont.)

Thickness	Const.#	Plywood Description	Allowable Roof Loads (psf) - Spacing of Supports, Center to Center				
			12	16	24	32	48
	1.	Group 1					123**
	2.	Group 1 face, back					109
	3.	Group 2					89**
	4.	Group 3					82
1-1/8	5.	Ponderosa pine					84
	6.	Group 4					61
	7.	E. spruce (ext.)					94
	8.	E. spruce (int.)					85

* Allowable load limited by rolling shear
** Allowable load limited by bending strength

All other loads limited by deflection.

than comparisons based on span and Identification Index. In these tables the range of constructions summarized in Table 5 was used. To arrive at the tabulated values each combination of span, panel thickness, and panel construction was checked by calculating a value to meet deflection, bending strength, and rolling shear limitations. Values for MOE and f_b listed in Table 5 were used. For all constructions a value of 53 psi was used for rolling shear ($H_{allowable}$) with an exterior adhesive and 48 psi for an interior adhesive.

Table 6 is based on a similar table found in the American Plywood Association publication entitled Plywood Construction Systems for Commercial and Industrial Buildings, January, 1970 (6). Table A in that publication established allowable roof loads associated with plywood of different species and standard thicknesses.

The thicknesses used in Table 6 range from 5/16- to 1-1/8-inches. The plywoods were compared over fewer spans than those normally considered by the American Plywood Association. All spans that were considered (12, 16, 24, 32, 48 inches o.c.) are evenly divisible into 96 inches. For each thickness, loads were calculated only for spans considered standard and reasonable (i.e.,5/16-inch material was not considered for a 32-inch span. By the same reasoning 1-1/8-inch material was not considered for a short span such as 16 inches.)

Calculations of the maximum allowable roof loads were based on the following procedures and assumptions. The plywood was considered to act as a continuous beam over two or more spans with the face grain perpendicular to the supports. Calculation formulas used are those found in the Timber Construction Manual, section 7, page 43, example 29 (1). Limiting factors for this use of plywood are the uniform live load deflection limitation of 1/240 of the span, the extreme fiber stress in

bending and rolling shear. Values for the Moment of Inertia and Effective Section Modulus are based on standard plywood construction.

Deflection Calculations

$$\Delta \text{ Max} = \ell / 240 = \frac{w \ell^4}{185 EI}$$

$$w = \frac{\frac{\ell}{240} \times 185 EI}{\ell^4} = \frac{.771 EI}{\ell^3}$$

w = lb./in.

$W = w \ell$

$W_{psf} = W \times 12/\ell$

W_{psf} = Allowable roof load (psf) = $w \times 12$

$$W_{psf} = \frac{9.852 EI}{\ell^3}$$

Uniform live load deflection limitation = $\ell / 240$ where ℓ = span in inches.

E = Modulus of Elasticity of the face and back veneers
I = Moment of Inertia for the plywood section

Bending Calculations

$$M_{max} = f_b \times KS$$

$$\frac{9 W \ell}{128} = f_b \times KS$$

$$W = \frac{128 \times f_b \times KS}{9 \ell}$$

Allowable live roof load (psf) = $W \times 12 / \ell$

Where: f_b = Extreme fiber in bending

M_{max} = Maximum moment

KS = Effective section modulus

Rolling Shear Calculations

$$H = \frac{V\,Q}{I\,b}$$

$$W = w\,\ell$$

$$V = 5/8\ W$$

$$H_{calculated} = \frac{5/8 \times W}{I/Q \times b}$$

$$H_{calculated} = \frac{.052\ W}{I\ /\ Q}$$

$$\frac{H_{allowable}}{H_{calculated}} \times \text{Allowable live load} = \text{Allowable live load based on rolling shear}$$

Where: $H_{allowable}$ = Allowable horizontal shear (psf)

$H_{calculated}$ = Actual horizontal shear (psf)

W = Load on the beam for a particular span (lbs.) from one of the preceding equations, whichever is limiting

V = Total vertical shear

I/Q = Rolling shear constant

b = 12 inches

By comparing the tabulated results of Tables 4 and 6 one is able to discern two rather important points. One is the correlation between an increase in thickness required to meet minimum EI and fKS values and what appears to be a minimum allowable roof load of 50 psf. An example of this is found in Table 4 Identification Index 24/0. Notice that when going from a Group 1 panel to a group 2 panel the thickness required increases from 3/8- to 1/2-inch. Comparing this with allowable loads in Table 6, one sees that in the 24-inch support spacing column and the 3/8-inch panel thickness rows, calculations of allowable loads place the Group 2 panel in a position of being unable to carry at least a 50 psf

load. This same phenomenon is in evidence for a 32-inch span also; but when considering a 48-inch span, 50 psf does not appear to be the cut-off point; rather, a value around 35 psf seems to be the limit. Table 23-A of Volume I of the 1970 edition of the Uniform Building Code (25), identifies minimum unit live loads for various building types. The practical implication is that a designer who is aware of the above cut-off points, minimum unit live loads as identified in a building code, and allowable live loads such as those in Table 6 is in a better position to choose the most appropriate plywood for roof sheathing.

Table 6 lends itself to a similar analysis in identifying particular constructions of ponderosa pine and Engelmann spruce that can compete with the West Coast "whitewoods", Douglas fir, and southern pine. This time the comparative property is load carrying ability based on a specified live load and a deflection limit of 1/240 of the span, rather than thickness and identification index required to meet a minimum EI and fKS.

Examination of Table 6 allows the following observations:

1) First, at no time can Construction 6 compare with Constructions 1, 2, 3, or 4. This follows directly from the fact that all of these panels have been assigned higher stiffness, strength, and rolling shear values in the APA Plywood Design Specification. It can also be seen that at no time does a panel of Construction 4 carry the same load as an equal thickness panel of Constructions 1, 2, or 3 for the same reason. However, the authors believe these comparisons could be of value to the designer who knows what specific roof loads are required for the building location. Quite possibly

by using a Group 1 or 2 panel instead of ponderosa pine or Engelmann spruce the roof would be unnecessarily overdesigned.

2) More significantly, when the 50 psf and 35 psf cut-off points mentioned above are considered, some rather interesting observations can be made:

a) For the 5/16-inch thick panels with a 16-inch span both ponderosa pine and Engelmann spruce plywoods (Constructions 4 and 6) meet the 50 psf minimum.

b) The same can be said for 1/2-inch thick panels for a 24-inch span, 5/8 and 3/4-inch thick panels, respectively, for a 32-inch span, and 7/8 and 1-1/8-inch panels, respectively, for a 48-inch span.

3) When one considers Construction 5, which is based on the procedures used by the APA in applying ASTM D2555 criteria, and Constructions 7 and 8, which are based on tests conducted at Colorado State University, another frame of comparison is possible. The derivation of stiffness and strength values for Construction 5 indicates that C-D ponderosa pine plywood is stiffer than its assigned Group 3 stiffness but not as strong in bending as expected of a Group 3 species. The test results on C-D, 5-ply, parallel laminated Engelmann spruce indicate that this species and grade of plywood has a much higher MOE than normally considered for C-D Group 4 panels and an exceptionally high f_b when compared with Group 4 assigned bending strength. Although this evidence is preliminary and will require further verification, the fact that such a discrepancy exists between the commercial species grouping values assigned to Group 4 and the Colorado State University test values that indicate a high retention of clear wood stiffness and

strength for C-D veneers suggests that more consideration should be given to assigning stiffness and strength values on an individual species basis, rather than by broad group classification.

Table 7 deals with plywood used as floor sheathing and the same approach was used as in Table 6. Allowable loads are expressed in psf (live load) and associated with a particular plywood composition, thickness, and flooring span. Thickness and spans for which values were developed are slightly different than in the roofing table. Thicknesses range from 1/2-inch to 1-1/4-inch and spans used were 12, 16, 20, 24, and 48 inches, center to center.

The same stiffness, strength, and shear properties were used for each particular plywood construction as in Table 5. When calculating the allowable live load based on stiffness, an allowable deflection limitation of $\ell/360$ was used, as is customary. In calculating floor loads, the APA assumes that the plywood acts as a uniformly loaded beam over three or more spans (7); therefore, deflection (Δ) is given by the formula (7):

$$\Delta_{max} = \frac{4}{581} \times \frac{w\,\ell^4}{EI}$$

or

$$\frac{\ell}{360} = 4 / 581 \left(\frac{w\,\ell^4}{EI} \right)$$

$$W = w\,\ell$$

$$W_{psf} = W \times 12 / \ell$$

$$W_{psf} = \frac{4.8417\ EI}{\ell^3}$$

Where: w = Load per unit length (lb./in.)

ℓ = Span (inches)

W = Load on the beam for a particular span (lbs.)

W_{psf} = Allowable live load (psf)

TABLE 7. ALLOWABLE FLOOR LOADS FOR PLYWOOD STANDARD SHEATHING

Thickness	Const.#	Plywood Description	Allowable Floor Loads (psf) - Spacing of Supports, Center to Center				
			12	16	20	24	48
1/2	1.	Group 1	378*	210	110		
	2.	Group 1 face, back	377*	209	108		
	3.	Group 2	339**	176	92		
	4.	Group 3	332	140	73		
	5.	Ponderosa pine	341	143	75		
	6.	Group 4	249	105	55		
	7.	E. spruce (ext.)	383	162	84		
	8.	E. spruce (int.)	343	143	75		
5/8	1.	Group 1	505*	368	192	111	
	2.	Group 1 face, back	498*	360	187	108	
	3.	Group 2	477**	307	160	93	
	4.	Group 3	477**	245	128	74	
	5.	Ponderosa pine	448**	252	131	75	
	6.	Group 4	400**	184	96	56	
	7.	E. spruce (ext.)	558*	282	147	85	
	8.	E. spruce (int.)	505*	253	132	76	
3/4	1.	Group 1		467**	292	169	21
	2.	Group 1 face, back		457**	286	165	20
	3.	Group 2		340**	243	140	17
	4.	Group 3		340**	194	112	14
	5.	Ponderosa pine		320**	199	115	14
	6.	Group 4		280	146	84	10
	7.	E. spruce (ext.)		429	223	129	16
	8.	E. spruce (int.)		386	196	117	14
7/8	1.	Group 1			457**	300	37
	2.	Group 1 face, back			403**	264	33
	3.	Group 2			332**	250	31
	4.	Group 3			332**	200	25
	5.	Ponderosa pine			313**	205	25
	6.	Group 4			250	150	19
	7.	E. spruce (ext.)			398	230	29
	8.	E. spruce (int.)			358	205	26
1-1/8	1.	Group 1					64
	2.	Group 1 face, back					56
	3.	Group 2					53
	4.	Group 3					42
	5.	Ponderosa pine					44
	6.	Group 4					32
	7.	E. spruce (ext.)					49
	8.	E. spruce (int.)					44
1-1/4	1.	Group 1					83
	2.	Group 1 face, back					75
	3.	Group 2					70
	4.	Group 3					56
	5.	Ponderosa pine					57
	6.	Group 4					42
	7.	E. spruce (ext.)					64
	8.	E. spruce (int.)					57

* Allowable load limited by rolling shear
** " " " " bending strength

All other loads limited by deflection.

Bending strength calculations for flooring are based on the following formula:

$$M_{max} = fKS$$

$$M_{max} = \frac{W \ell}{10}$$

$$\frac{W \ell}{10} = fKS$$

$$W = \frac{10\ fKS}{\ell}$$

$$W \times 12/\ell = W_{psf}$$

And the rolling shear calculations are based on the formula:

$$H = \frac{V\ Q}{I\ b}$$

$$W = w \ell$$

$$V = 5/8\ W$$

$$H_{calculated} = \frac{5/8 \times W}{I/Q \times b}$$

$$H_{calculated} = \frac{.052\ W}{I/Q}$$

$$\frac{H_{allowable}}{H_{calculated}} \times \text{Calculated Allowable Live Load in Bending} = \text{Allowable Live Load in Rolling Shear}$$

Analysis of Table 7 points to comparisons similar to those for Table 6, in that ponderosa pine and Engelmann spruce plywoods often may be satisfactory for a flooring application in which use of a Group 1 or 2 species may be "overdesigned". However, in this table there do not appear to be cutoff points similar to the 50 psf or 35 psf loads in the roof-load table. Also similar observations may be made about the higher than usual stiffness and strength C-D Engelmann spruce veneers compared to the clear wood values for these species.

Wall Sheathing

Wall sheathing is another major use of plywood in which ponderosa pine and Engelmann spruce may be able to find niches in which they can compete favorably with the Group 1 and 2 plywood species. Plywood applied to the wall studs is roughly twice as rigid as diagonally applied boards (5). The same grades of plywood used for roof sheathing are recommended for use in wall sheathing. Table 8 reproduced below is taken from the APA Plywood Construction Guide (5). From this table it is possible to pinpoint some definitely advantageous marketing niches for Rocky Mountain species. For example, the maximum stud spacing allowed for a 5/16-inch panel is 16 inches. A 5/16-inch Douglas fir panel would carry an Identification Index of 20/0 whereas a ponderosa pine panel of the same thickness would be a 16/0 and an Engelmann spruce panel only a 12/0. The use of a 20/0 panel is obviously unnecessary if a stud spacing of 16 inches is specified; a builder could be encouraged to go to the lower span index ratings to do the same job.

Further analysis of 3/8-inch and 1/2-inch wall sheathing points to additional niches where ponderosa pine and Engelmann spruce fulfill minimum requirements. In 3/8-inch thickness, a Douglas fir panel would have a 24/0 index, a ponderosa pine panel would have a 20/0 index and Engelmann spruce would have a 16/0 index. In 1/2-inch thickness, a Douglas fir panel would carry a 32/16 index and ponderosa pine and Engelmann spruce would be marked 24/0.

The Identification Indexes discussed above are as outlined by the American Plywood Association when relating span indexes and species.

Based upon the above analysis, it appears that the wall sheathing market is a good potential area for ponderosa pine and Engelmann spruce producers to explore.

Special Constructions

With the preceding tables and discussion as background, the question comes to mind, "How can ponderosa pine and Engelmann spruce compete better in the sheathing market?" To help answer this question an examination of special plywood constructions was made.

The stiffness and strength relationships presented below are derived by taking the ratio of the pertinent Group 1, 2, or 3 property to the equivalent Engelmann spruce or ponderosa pine property.

Example Calculations: Group 1 versus Engelmann spruce (based on Group 4 values)

Stiffness Relationships

$$\frac{E_{\text{Group 1}}}{E_{\text{Engelmann spruce}}} = \frac{1{,}800{,}000 \text{ psi}}{900{,}000 \text{ psi}} = 2.00$$

Strength Relationships

$$\frac{f_{b\ \text{Group 1}}}{f_{b\ \text{Engelmann spruce}}} = \frac{1{,}650 \text{ psi}}{1{,}000 \text{ psi}} = 1.65$$

The stiffness and strength values used for the individual groups are those given in Table 5. Comparisons of Engelmann spruce and ponderosa pine against Group 1, Group 2, and Group 3 plywoods in stiffness and strength are summarized below:

ENGELMANN SPRUCE (Construction 6, MOE = 900,000 psi; f_b = 1,000 psi)

Versus	Stiffness Relationship $\left(\frac{E}{E_{spruce}}\right)$	Strength Relationship $\left(\frac{f}{f_{spruce}}\right)$
Group 1	2.00	1.65
Group 2	1.66	1.20
Group 3	1.33	1.20

PONDEROSA PINE (Construction 4, MOE = 1,200,000 psi; f_b = 1,200 psi)

Versus	Stiffness Relationship $\left(\frac{E}{E_{p.pine}}\right)$	Strength Relationship $\left(\frac{f}{f_{p.pine}}\right)$
Group 1	1.50	1.38
Group 2	1.25	1.00

From these calculations it can be seen that for a Group 4 spruce panel to match a Group 1 panel of the same thickness in stiffness and strength, its moment of inertia would have to be doubled and its section modulus increased by a factor of 1.65; to match a Group 2 panel it would have to have a moment of inertia increase of 1.66 and a section modulus increase of 1.20. A similar analysis can be made for a Group 3 ponderosa pine panel.

To accomplish these necessary increases in I and KS, all a plywood producer would have to do is increase veneer and panel thicknesses; however, he must adhere to veneer and panel thickness tolerances established in PS 1-66. For this reason an attempt is made in Table 9 to suggest certain constructions of ponderosa pine and Engelmann spruce plywood within the tolerance limits of PS 1-66 that a manufacturer could use to compete mechanically with Group 1 and 2 plywoods.

Under present PS 1-66 standards, C-C Exterior and Standard plywood of Group 4 woods may be marked with the same Identification Index as plywood made of Group 3 woods if the 5/16-, 3/8-, 5/8-, 3/4-, and 7/8-inch thick panels are manufactured 1/32-inch thicker than standard nominal thickness, and if the 3/4- and 7/8-inch constructions have 1/8-inch minimum thickness faces and backs (28). However, PS 1-66 allows no such special construction in which a panel of Group 3 species is permitted to carry the same Identification Index as a Group 2 panel, nor is a Group 4 plywood able through panel and veneer thickness increases

TABLE 9. SPECIAL PLYWOOD CONSTRUCTIONS (Moment of Inertia, Section Modulus, and Increase Factors)

Part One - Standard Plywood Constructions

Begin. Nominal Thick-ness	Actual Thick-ness	Veneer Thickness	Moment Of Inertia	Effect. Section Modulus (KS)
5/16 .312	.300	F & B .1 Center .1	.026	.147
3/8 .375	.388	F & B .1 Center .188	.047	.215
1/2 .500	.500	F & B .1 Center .1 X-bands .1	.100	.339
5/8 .625	.638	F & B .1 Center .188 X-bands .125	.171	.466
3/4 .75	.762	F & B .1 Center .188 X-bands .188	.261	.591
7/8 .875	.874	F & B .1 Center .188 X-bands(3) .1	.418	.813
1-1/8 1.125	1.138	F & B .1 Center .188 X-bands(3).188	.724	1.093

Part Two - Modified Plywood Constructions to Improve Stiffness and Strength

Mod. Veneer Thick-ness	Actual Thick-ness	Moment of Inertia	Increase Factor (I)	Effect. Section Modulus (KS)	Increase Factor (KS)
F & B .111 Center .1	.321	.032	1.23	.170	1.16
F & B .125 Center .125	.375	.051	1.08	.231	1.07
F & B .155 Center .1	.410	.068	1.45	.282	1.31
F & B .111 Center .083 X-bands .1	.505	.105	1.05	.353	1.04
F & B .150 Center .063 X-bands .084	.531	.147	1.49	.472	1.39
F & B .131 Center .125 X-bands .125	.636	.205	1.20	.547	1.17
F & B .166 Center .125 X-bands .1	.658	.254	1.48	.656	1.41
F & B .110 Center .178 X-bands .188	.774	.293	1.12	.644	1.09
F & B .167 Center .188 X-bands .125	.770	.382	1.46	.843	1.43
F & B .150 Center .137 X-bands(3) .1	.874	.465	1.11	.905	1.11
F & B .188 Center .125 X-bands(3) .1	.925	.614	1.47	1.13	1.39
F & B .140 Center .148 X-bands(3) .188	1.14	.835	1.15	1.25	1.14
F & B .150 Center .188 X-bands(3) .168	1.18	1.03	1.43	1.48	1.36

to carry a stamp equivalent to Group 2 species panels.

The authors wish then to demonstrate that without exceeding PS 1-66 panel and veneer thickness tolerances it is possible to make Group 4 and Group 3 panels that are equal in stiffness and strength to Group 2 and Group 1 panels even though they may not be grade marked to show this equivalency. The tolerance limits of PS 1-66 are summarized as follows:

> Overall panel thicknesses must fall within the tolerance limits of + or - 1/32 (.0312) of an inch of the specified panel thickness for panels up to a thickness of 13/16-inch and + or - 5 percent of the specified thickness for panels over 13/16-inch (Section 3.9.1 of PS 1-66). Veneer thicknesses should maintain 1/10-inch or thicker in panels 3/8-inch or over and 1/12-inch or thicker in panels of lesser thicknesses. The use of veneers 1/16-inch or thicker in 5-ply, 3/8-inch exterior panels and as centers only in other 5-ply panels is allowed. Also veneers of 1/12-inch or thicker may be used as core in 5-ply, 1/2-inch panels. At no time should veneers thicker than 1/4-inch be used in the special construction (Section 3.3.6 of PS 1-66) (28).

Table 9 contains two special constructions developed for each nominal plywood thickness (5/16-inch being an exception). The first special construction was derived in such a way that an increase in moment of inertia and section modulus was realized while the overall thickness of the panel was not increased by more than two percent. Percentage increases in the moment of inertia that resulted from this very minor thickness increase ranged from 6 to 20 percent and increases in the section modulus ranged from 7 to 17 percent.

The second construction was developed by modifying the panel to what was considered to be a maximum practical limit yet still allow a rather substantial increase in moment of inertia (43-49 percent increase) and section modulus (31-43 percent increase).

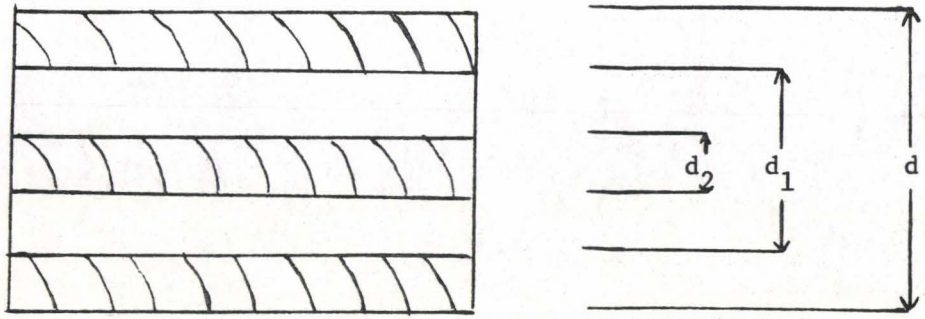
Table 9 is presented in two parts. Part One is a presentation of standard plywood constructions taken directly from Tables A2.2.1 and 2.10.1 of the Plywood Design Specification. Part Two is a breakdown of veneer thickness modifications and the resulting moment of inertia and effective section modulus. The increase factor columns are the ratio of the new moment of inertia and section modulus to the standard values given in Part One.

Figure 2 is an example of standard 1/2-inch, 5-ply construction and a summary of the calculations used in determining moment of inertia and section modulus. In Figure 3 examples are given of how both very conservative and extreme modifications in veneer thicknesses and overall panel thickness may result in substantial percentage increases in moment of inertia and section modulus.

Another option in applying factors given in Table 9 is to use Colorado State University test values for Engelmann spruce. Comparisons of Engelmann spruce constructions 7 and 8 with Groups 1, 2, and 3 are given below. The stiffness and strength values used for the individual groups are those given in Table 5.

ENGELMANN SPRUCE (Interior Glue Line - Construction 8, MOE = 1,240,000 psi; f_b = 2400 psi)

Versus	Stiffness Relationship $\left(\frac{E}{E_{spruce}}\right)$	Strength Relationship $\left(\frac{f}{f_{spruce}}\right)$
Group 1	1.45	No increase necessary
Group 2	1.21	No increase necessary
Group 3	No increase necessary	No increase necessary



Moment of Inertia is a Factor that Affects the Stiffness of Plywood and Effective Section Modulus Affects the Bending Strength

MOMENT OF INERTIA (I)

$$I_{11} = \frac{b\,d^3}{12} - \frac{b\,d_1^3}{12} + \frac{b\,d_2^3}{12}$$

$$I_{\perp} = \left[\frac{b\,d_1^3}{12} - \frac{b\,d_2^3}{12}\right] \frac{1}{35}$$

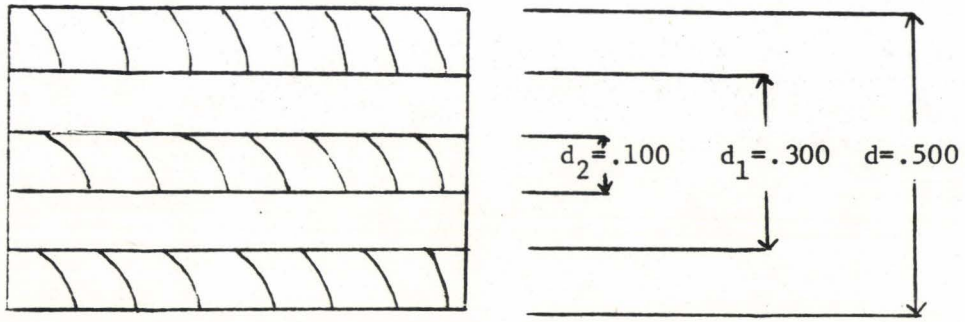
$$I = I_{11} + I_{\perp}$$

EFFECTIVE SECTION MODULUS (KS)

$$KS = \frac{I}{.5\,d} \times .85$$

STANDARD 1/2", 5-PLY CONSTRUCTION

All Plys .100 inches



$$I_{11} = (.500)^3 - (.300)^3 + (.100)^3 = .099 \text{ in.}^4$$

$$I_{\perp} = \left[(.300)^3 - (.100)^3\right] \frac{1}{35} = .0007 \text{ in.}^4$$

$$I = I_{11} + I_{\perp} = .0997 \text{ in.}^4$$

APA Value .100 in.^{4}

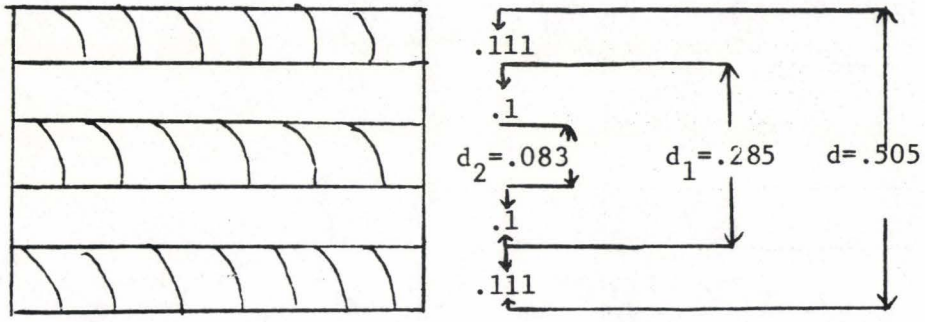
$$KS = \frac{.100}{.5(.5)} \times .85 = .340 \text{ in.}^3$$

APA Value .339 in.^{3}

FIGURE 2. STANDARD 1/2", 5-PLY CONSTRUCTION

MODIFIED PLYWOOD CONSTRUCTION #1

Zero to 2% Increase in Overall Panel Thickness Resulting in a 5-20% Increase in Moment of Inertia and a 4-17% Increase in Section Modulus.



$I = .105 \text{ in.}^4$

I/I_{APA} = Increase Factor

.105/.100 = 1.05

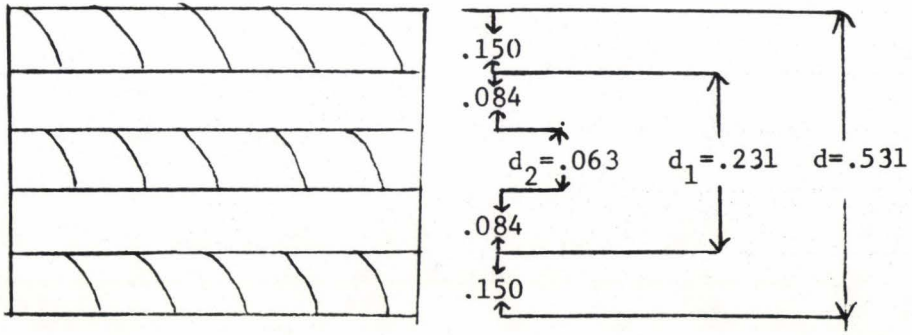
$KS = .353 \text{ in.}^3$

KS/KS_{APA} = Increase Factor

$\frac{.353}{.339}$ X 1.04

MODIFIED PLYWOOD CONSTRUCTION #2

Modification to Achieve a Maximum Practical Increase in I



I = .147

Increase Factor = 1.47

KS = .472

Increase Factor = 1.39

FIGURE 3. MODIFIED PLYWOOD CONSTRUCTIONS

ENGELMANN SPRUCE (Exterior Glue Line - Construction 7, MOE = 1,380,000 psi; f_b = 2740 psi)

Versus	Stiffness Relationship	$\frac{E}{E_{spruce}}$	Strength Relationship	$\frac{f}{f_{spruce}}$
Group 1	1.39		No increase necessary	
Group 2	1.09		No increase necessary	
Group 3	No increase necessary		No increase necessary	

The above ratios allow some interesting comparisons although further verification of the applicability of testing procedures is necessary before firm conclusions can be made about the high stiffness and strength values found in Colorado State University tests for Engelmann spruce C-D grade veneer. To boost an Engelmann spruce panel bonded with interior glue to the same stiffness as a Group 1 panel would require a moment of inertia increase of 45 percent---a fairly simple and permissible procedure by increasing veneer thicknesses. To match a Group 2 panel would require a 21 percent increase. A similar analysis is possible for Engelmann spruce plywood bonded with exterior adhesives. Where the author has indicated "no increase necessary," the stiffness or strength of the spruce panel is already as high or higher than the group it is being compared with; therefore, no modification of veneer thicknesses is required.

Other Special Construction

Another option available to Engelmann spruce or ponderosa pine plywood producers is to use Group 1 or Group 2 plywood species as the face and back of sheathing panels. According to PS 1-66 (28), inner plys may be of any species with a specific gravity of 0.41 or more based on green volume and over-dry weight. The face and back species of a plywood panel determine its species grouping, therefore, a panel with Group 1 face and back with Group 3 (ponderosa pine) or Group 4 (Engelmann spruce) inner plys would be permitted to carry an identification index of a Group 1 panel.

Underlayment

Underlayment is another primary use of plywood that has possibilities for the application of Engelmann spruce and ponderosa pine plywood. Prime requirements of a panel used as underlayment are that it be dimensionally stable and that it will not "hump-up" around nails. These requirements are as well satisfied by ponderosa pine and Engelmann spruce as by any other plywood species.

Technical requirements for this specially stamped plywood product are that the face must be C-plugged, the back must be at least D veneer,

and the inner plys both C-and D-grade with a C-grade veneer immediately under the C-plugged face. The face should be touch-sanded or fully sanded, as specified, with fully sanded panels recommended for uses where thin resilient floor coverings are to be placed over the underlayment (5, 6). Three-eighths-inch thick underlayment is the most common thickness used.

Integrity of surface is a key factor in determining to what extent plugs are required in the C-grade face veneer. It is the author's opinion that Engelmann spruce is ideally suited for this use because of its relatively few knotholes and ponderosa pine is also well suited because of its ease of working. Since there is less contrast between early and late wood in the two study species than in Douglas fir or the southern pines, the telegraphing effect often seen through thin surface coverings should be reduced by the use of Engelmann spruce or ponderosa pine as underlayment.

Other Physical Properties

Nail Withdrawal

Another critical plywood property is nail withdrawal. Values for this property are presented in Table 10. The basis for this table is the formula developed from tests of solid wood (37):

$$P = 1380\ (G)^{5/2}\ D$$

Where:
- P = Allowable nail withdrawal resistance in pounds per inch of nail penetration used in designing for normal duration of load
- 1380 = Empirically developed constant
- G = Species specific gravity based on O.D. weight and O.D. volume
- D = Diameter of the nail

Since this equation was developed for solid wood, its application to plywood may be an approximation.

The following specific gravities, based on Wood Handbook values, were used in the above equation for calculating nail withdrawal:

TABLE 10. CALCULATED APPROXIMATE NAIL WITHDRAWAL LOADS FOR VARIOUS PLYWOODS (a) (b)

Plywood Thickness	Plys	Nail Size	Douglas Fir		Douglas Fir Faces w/ Engelmann Spruce Core		Ponderosa Pine		Engelmann Spruce	
			Allowable Nail Withdrawal Resistance Per Nail	Allowable Nail Withdrawal Resistance/ $ft.^2$ Roof	Allowable Nail Withdrawal Resistance Per Nail	Allowable Nail Withdrawal Resistance/ $ft.^2$ Roof	Allowable Nail Withdrawal Resistance Per Nail	Allowable Nail Withdrawal Resistance/ $ft.^2$ Roof	Allowable Nail Withdrawal Resistance Per Nail	Allowable Nail Withdrawal Resistance/ $ft.^2$ Roof
			lb.	lb.	lb.	lb.	lb.	lb.	lb.	lb.
5/16	3	3d	7	44	6	35	4	26	4	23
3/8	3	3d	9	53	7	42	5	31	5	28
1/2	5	3d	12	71	8	48	7	41	6	37
5/8	5	3d	15	88	10	61	9	51	8	47
3/4	5	3d	18	106	12	73	10	61	9	56
7/8	7	3d	21	124	13	78	12	72	11	65
1-1/8	7	4d	29	173	19	112	17	102	14	84
1-1/4	7	4d	29	177	21	124	19	114	17	101

(a) Allowable nail withdrawal resistance per square foot of roof based on an average of 6 nails per square foot of roof surface and using wood shingles.

(b) All nail withdrawals rounded to the nearest pound.

Douglas fir		.51
Douglas fir faces	3 ply	.47
and Engelmann	5 ply	.44
spruce inner plys	7 ply	.43
Ponderosa pine		.42
Engelmann spruce		.40

The specific gravity values for Douglas fir panels with Engelmann spruce inner plys were developed by using a weighted value based on the number of plys of each species.

Page 173 of the Wood Handbook contains some general statements on nail withdrawal resistance of plywood:

> "The nail-withdrawal resistance of plywood is 15 to 20 percent less than that of solid wood of the same thickness."
>
> "The withdrawal resistance per inch of penetration decreases with increase in the number of plys." (37).

Correspondence with the Product Research Department of the American Plywood Association indicates that, from the tests they have conducted, nail withdrawal resistance of 5/16- and 3/8-inch plywood appeared comparable to that of nominal 1-inch lumber. Also limited APA studies comparing the properties of 3-ply, 1/2-inch plywood with 5-ply, 1/2-inch plywood found no significant difference between nail withdrawal data for the two constructions. Therefore, within the limits of their data, the APA information does not seem to support the Wood Handbook statements (37).

As noted in the Wood Handbook, plywood's resistance to splitting gives it an advantage over lumber in regard to nail holding. Also, when applying shingles, the possibility of running a nail completely through the piece, i.e., a knot hole in lumber, is eliminated when using plywood. Therefore, from a practical standpoint, several factors seem to favor the ability of plywood sheathing to provide adequate resistance to nail withdrawal (37).

The American Plywood Association also states that, except in extreme Southern Florida, roofing nails need only develop a withdrawal resistance of 25 pounds per square foot of roof surface to withstand the most severe storms (5). As can be seen in Table 10, all 4 of 5 plywoods develop sufficient nail withdrawal resistance (25 psf of roof surface) except 5/16-inch thick Engelmann spruce plywood.

Panel Weight

The next technical property comparison made is that of panel weight as presented in Table 11. This table is not a completely accurate panel weight comparison because the calculations are based on clear wood specific gravity values rather than plywood specific gravities; however, the relationship between the three species should be relatively accurate. A light weight panel has a two-fold advantage, the first being lower costs in shipping it from producer to consumer and the second being greater ease of handling in applying the panels to studs and joists. As the reader can quickly discern from Table 11 both Engelmann spruce and ponderosa pine have a definite weight advantage that should be useful.

Machining

The next property to be considered in trying to determine technical advantages and disadvantages of Engelmann spruce and ponderosa pine plywood is machining. Machining is an important aspect in plywood utilization when one considers plywood's many uses in specialty products and industrial markets. Most plywood products other than sheathing require a high grade face that is usually sanded. Some examples of high grade and/or smooth types of panels are marine panels, concrete form panels, decorative siding panels and overlaid panels. Machining in these types of panels is therefore important to the manufacturer as it affects his ability to patch, plug, and sand the panels.

TABLE 11. PLYWOOD WEIGHT PER SQUARE FOOT/ WEIGHT PER 4-X 8-FOOT PANEL (POUNDS) AT 12% MOISTURE CONTENT.

Panel Thickness	Douglas Fir SG = .48	Ponderosa Pine SG = .40	Engelmann Spruce SG = .35
5/16	.98 / 28	.82 / 23	.72 / 21
3/8	1.04 / 34	.87 / 28	.77 / 25
1/2	1.40 / 45	1.17 / 37	1.03 / 33
5/8	1.75 / 56	1.46 / 47	1.29 / 41
3/4	2.10 / 67	1.75 / 56	1.55 / 50
7/8	2.45 / 78	2.04 / 65	1.81 / 58
1-1/8	3.14 / 100	2.62 / 84	2.31 / 74
1-1/4	3.50 / 112	2.92 / 93	2.58 / 83

Specific gravity for Douglas fir and ponderosa pine is based on oven-dry weight and air-dried volume (12% moisture content) as given in the Wood Handbook. A S.G. of .35 for Engelmann spruce is a recently developed value from U.S. Forest Service Research Paper FPL 128, January, 1970.

When plywood reaches an industrial user, its machining characteristics become important as it is transformed into various end-products. Although such industrial end uses are almost limitless, a partial list would have to include such major uses as boxes, pallets, air cargo containers, recreational and commercial trailers, signs, tables, and cabinets.

Table 12 is taken directly from information contained in a similar table in the U.S.D.A Forest Products Laboratory Wood Handbook #72 (37). Analysis of such woodworking comparisons is subjective at best and serves only as a broad generality. Since no data appear to be available on the response of various softwoods to power tools little else can be said except to make the following broad assumptions:

1. Ponderosa pine plywood should respond quite satisfactorily to power tool machining and relatively speaking it should respond better than Douglas-fir, western larch, and southern yellow pine (major Group 1 plywood species) and most Group 2 species.
2. With no data available on Engelmann spruce, an assumption must be made that the machining performance of this species should be comparable to that of eastern and Sitka spruce. These two species show a slight edge on the Group 1 woods and are on the whole the same as Group 2 woods in machining.

Color

In many industrial and residential applications of plywood color is a factor of some importance, even if the exposed surface is to be stained or painted. Color is another subjective characteristic that is usually a function of individual preference. However, it is probably safe to assume that a light, even color would be preferable if a lightly pigmented stain or paint is to be applied. Light, even color would also be desirable in assuring the

TABLE 12. CLASSIFICATION OF CERTAIN SOFTWOOD SPECIES ACCORDING TO EASE OF WORKING WITH HAND TOOLS *

Group 1 - Easy to Work	Group 2 - Relatively Easy To Work	Group 3 - Least Easy To Work
Western White Pine	Fir, White	Douglas Fir
Ponderosa Pine	Hemlock, Western	Pine, Southern Yellow
Port Orford Cedar	Spruce, Eastern	
	Spruce, Sitka	

* U.S.D.A. Forest Products Laboratory Wood Handbook #72 (37).

legibility of stencils on plywood surfaces. Based on this assumption is is logical to assume that the smooth, even, white appearance of Engelmann spruce veneer is particularly well suited for painting when compared to Douglas-fir and southern yellow pine although a less distinct advantage is present when it is compared to western hemlock, white fir, and other Group 2 woods. Ponderosa pine is probably not quite as desirable as Engelmann spruce when considering color, but a ponderosa pine panel is still well within acceptable limits and may be more desirable than Douglas-fir and southern pine.

Painting

According to the Wood Handbook, the painting characteristics of plywood are essentially those of solid lumber of the kind used for the face ply. Care should be taken in applying the ratings of Table 13 to plywood since it was based on select grades of wood. Because softwood veneer is almost exclusively rotary-cut, it has flat-grained faces that display irregular bands of summer wood. This type of surface therefore requires careful choice of primers and paints for best results because of variation in density and texture. Moreover, the face plys of plywood are often more susceptible to checking than is lumber (37).

Correspondence with V. P. Miniutti of the Forest Products Laboratory indicates that no attempt has been made to rate plywood species for paintability. Recommendations by the Laboratory include the use of overlays when painting plywood. Otherwise it should be stained or treated with a water-repellent preservative.

Based on Table 13, it appears that both ponderosa pine and Engelmann spruce hold marked advantage over Douglas-fir and southern pine plywoods.

TABLE 13. GROUPING OF CERTAIN SELECTED SOFTWOODS FOR EXTERIOR PAINTING*

Group 1[a]	Group 2[b]	Group 3[c]	Group 4[d]
Port Orford Cedar	Western White Pine	Commercial White Fir Engelmann Spruce Ponderosa Pine Western Hemlock	Douglas Fir Southern Yellow Pine Western Larch

* Taken from Table 42 of the Forest Products Laboratory Wood Handbook #72 (37).

a. Wood on which paints of the widest range in kind and quality give good service.

b. Wood on which care is needed to select a suitable priming paint, such as pure white lead or a zinc-less house paint primer.

c. Woods more exacting than those of Group 2 but less exacting than those of Group 4 in requirements of suitable priming paint, finish paint of high quality, and careful choice of program of maintenance.

d. Woods that need most careful selection of suitable paints, and for which aluminum house paint is particularly desirable for priming when the wood is first painted, with a zinc-less house paint primer as second choice if for any reason aluminum paint cannot be used.

Quite possibly Engelmann spruce has been underrated since there is no significant contrast between summer and spring wood bands.

Weathering

Another characteristic of wood that is difficult to define is its weatherability. Weathering may involve change in color, roughening, and checking of the surface. A problem with exposed solid wood is that of cupping and twisting due to uneven stresses on the face and back of the exposed board (37). Because of plywood's exceptional dimensional stability these problems are to a great extent eliminated. According to Perkins (31), the average expansion of plywood across the width of a 48-inch by 96-inch panel is considered to be between .05 inch and .09 inch when going from 6 percent to 10 percent moisture content. Even under the most extreme moisture content changes the cross width expansion is not considered to exceed .15 inch. With this extremely small range of expansion and shrinkage it is not considered worthwhile to attempt to discuss differences between individual species in plywood dimensional stability.

Therefore, plywood weathering properties principally involve color changes and checking properties of the exposed face ply. When the surface of the plywood is exposed to repeated wetting and drying, the surfaces of the face veneers attempt to shrink and swell. The stresses resulting from the restraint of such shrinking and swelling result in compression set and ultimately in checking, which are more pronounced when the wood shrinkage values are large. According to the Wood Handbook, tangential shrinkage values expressed in percent are 6.3 for Western hemlock, 6.02 for Douglas-fir and the southern pines, 5.7 for white fir, 5.3 for Engelmann spruce, and 5.0 for ponderosa pine (37).

The Wood Handbook groups the weathering response of various woods in the following manner (certain selected softwoods only presented):

Woods That Weather With:	Light gray color and silvery sheen	Port Orford Cedar
	Light gray color and moderate sheen	Ponderosa Pine Western White Pine Eastern Spruce Sitka Spruce
	Dark gray color and little or no sheen	Douglas Fir Commercial White Fir Western Larch Southern Yellow Pine
Woods on Which Weather-Checks Are:	Inconspicuous	Port Orford Cedar
	Conspicuous	Douglas Fir White Fir Western Hemlock Western Larch Eastern Spruce Sitka Spruce Ponderosa Pine

Since the study species are either not listed or are listed under only one category, conclusions are hard to draw from the above information. This is not to say, however, that ponderosa pine and Engelmann spruce would not perform as well as Douglas fir or the West Coast "whitewoods" in an exposed use such as textured sidings or some other decorative exterior application.

Gluability

A physical property of importance that may often be overlooked for plywood is that of gluability. The ability of wood to form good glue bonds over a wide range of glue types and gluing conditions is extremely important. This is especially true in the case of plywood manufacture and remanufacture since veneers that glue well only under certain

specified conditions limit the manufacturer to producing only certain panel products and makes use of his panels in the industrial market a problem.

Ratings of glue bonding properties are difficult to define because of the many glues and gluing methods available and the many different end-use conditions they must meet. Note that in Table 14 Engelmann spruce is not listed. Because of this it is assumed that its gluing properties would resemble those of Sitka spruce. If this assumption is valid, it would suggest that both Engelmann spruce and ponderosa pine (especially spruce) would be highly acceptable to gluing in manufacture and remanufacture. Ponderosa pine quite possibly is underrated in regard to its ease of gluing.

Acoustics

Acoustical insulation with building materials,

is becoming, or will become, increasingly important as residential construction emphasis shifts from single to multi-family units. It is necessary to speak of acoustical insulation as two separate phenomena when discussing the performance of various building materials. These two phenomena are sound transmission and sound absorption. Here, as in consideration of dimensional stability, there exist almost no species differences, but it is believed to be of importance to note a few points:

1. Major plywood products in which some degree of consideration must be given to acoustical performance are roof sheathing, subflooring, underlayment, combination flooring, wall sheathing, partitions, siding, soffits, interior paneling, and exterior sheathing.
2. More attention should be given to exploitation of acoustical performance of plywoods by manufacturers.

TABLE 14. CLASSIFICATION OF SOFTWOOD SPECIES ACCORDING TO GLUING PROPERTIES*

Group 1	Group 2	Group 3
Glue very easily with different glues under wide range of gluing conditions	Glue well with different glues under a moderately wide range of gluing conditions	Glue satisfactorily under well-controlled gluing conditions
Bald Cypress	Cedar, Eastern Red	Cedar, Alaska
Cedar, Western	Douglas Fir	
Fir, White	Hemlock, Western	
Larch, Western	Pine: Eastern White	
Redwood	Southern Yellow	
Spruce, Sitka	Ponderosa	

* Taken from Table 34, Wood Handbook #72 (37).

TABLE 15. THERMAL CONDUCTIVITY OF VARIOUS PLYWOODS AT 12% MOISTURE CONTENT

Species	Specific Gravity*	k (based on MacLean's Equation)	k (based on Wangaard's Alinement Chart)
Douglas Fir	.48	.993	.900
Southern Pine			
Loblolly	.51	1.045	.945
Longleaf	.58	1.166	1.050
White Fir	.37	.804	.720
Western Hemlock	.42	.890	.800
Ponderosa Pine	.40	.855	.770
Engelmann Spruce	.34	.752	.680

* Specific Gravity based on values as published in the Wood Handbook. (37)

Thermal Insulation

Thermal insulation is another relatively important property that is often overlooked. In many applications of plywood its thermal insulating qualities are of prime importance. Examples of such applications are interior linings of vans, linings of railcars, exterior sheathing, siding, roof and wall sheathing. The main factors influencing thermal conductivity of wood are the density, moisture content, and grain direction (42). Thermal conductivity through the thickness of plywood is essentially that of the same wood in the direction perpendicular to the grain (4).

MacLean's equation (27) for thermal conductivity at moisture contents below the fiber-saturation point is:

$$k = S\,(1.39 + .028\,M) + .165$$

Where: k = BTU inch per square foot, hour °F
S = Specific gravity based on oven-dry wood and volume at test
M = Moisture content, %

Using MacLean's equation it is possible to derive relationships comparing Engelmann spruce and ponderosa pine plywood with Douglas fir, the West Coast "whitewoods" and the southern pines. Wangaard (41) has also developed values for thermal conductivity by the use of an alinement chart and these values are also presented in Table 15.

As can be seen by Table 15, thermal conductivity increases with increasing specific gravity. Therefore, the lighter woods (Engelmann spruce particularly) should make a much better insulator.

A point that should be made concerning both acoustical and thermal insulation is that plywood's properties are only moderate when compared with the best insulating materials for these purposes. It is plywood's combination of strength and moderate insulation ability that makes it desirable.

Integrity of Surface

The degree to which defects (knots, knotholes, bark pockets, and pitch pockets) are found in the face plys of plywood is defined here as integrity of surface and is a property of some importance in many plywood uses. For example, a manufacturer using C-D sheathing grade plywood as a liner for trailers and vans desires a plywood with as few knotholes as possible so that when he staples a thin metal layer to the plywood the staples won't punch through.

To come up with some information on the integrity of surface of the study species and its competitors, a small scale study was carried out with the objective of determining the size and number of knots and knotholes and the percent of the face sheets that were defective. To do this the knots and knotholes in the face plys of some 300 sheets of C-D plywood were measured. The species studied were Douglas-fir, Engelmann spruce, and ponderosa pine. The Douglas-fir panels sampled came from Independence, Oregon; Medford, Oregon; and Missoula, Montana, while all of the ponderosa pine and a large portion of the Engelmann spruce was manufactured by Montezuma Plywood Company from trees harvested in the southwestern portion of Colorado. The remainder of the Engelmann spruce panels measured were produced by the Van Evan Company in Missoula, Montana, and it is assumed that this is the locality from which the timber was harvested. Only faces that graded C and D according to the information presented in PS 1-66 were used in the respective categories. If a sheathing grade panel was found to have a B face, the face was not included. This was done to eliminate manufacturing supply and demand variables. The results of the measurements are summarized in Table 16.

TABLE 16. COMPARISON OF KNOTS AND KNOTHOLES IN C-D GRADE DOUGLAS-FIR, ENGELMANN SPRUCE, AND PONDEROSA PINE PLYWOOD SHEATHING.

	DOUGLAS-FIR			ENGELMANN SPRUCE			PONDEROSA PINE		
	C	D	SIG.	C	D	SIG.	C	D	SIG.
Average Percentage Defective Area Due To Knots	.307	.414	N.S.	.537	.656	N.S.	.529	.970	**
Average Percentage Defective Area Due To Holes	.129	.305	***	.123	.108	*	.193	.229	N.S.
Average Number of Knots	21	18	N.S.	45	26	***	42	27	*
Average Number of Holes	10	11	N.S.	12	5	***	14	7	***
Average Percentage Defective Surface Per Knot	.012	.023	***	.012	.027	***	.011	.035	***
Average Percentage Defective Surface Per Hole	.013	.027	***	.011	.021	**	.012	.026	***
Average Percentage Defective Surface Area	.448	.738	***	.672	.823	*	.729	1.273	N.S.

N.S. - No Significant Difference
* - Significant Difference at .05 level
** - Significant Difference at .01 level
*** - Significant Difference at .001 level

As expected it was found that the average amount of defective surface was higher in grade D veneer than in C-grade but in only one species was this difference highly significant. In fact, there was no significant difference between C and D ponderosa pine. It was found that there were more numerous but smaller knots and knotholes in C-than D-grade, but the difference in the number of knots and knotholes was not significant in Douglas-fir, highly significant in Engelmann spruce, and of low to high significance in ponderosa pine. The difference in the size of these defects between the two grades was highly significant for all species. It is surprising to note that in comparing C-and D-grade faces the percentage of surface area defective due to knots and knotholes was highly significant only in the case of Douglas-fir knotholes. This means that based upon our limited sample there appears to be only slight differences in the amount of defective surface in C and D veneers of the three species.

It is interesting to note that the highest percentage of total defective surface was in D-grade ponderosa pine---a value of 1.273 percent or only 59 square inches out of a total of 4608 square inches in a 4 by 8 foot panel.

Species comparisons are summarized in Table 17 below by grade. Levels of significance are: N.S. - No Significant Difference, * Significant at .05 level, ** Significant at .01 level, and *** Significant at .001 level.

Some general conclusions can be drawn from this table concerning the integrity of surface of Douglas-fir, Engelmann spruce, and ponderosa pine C-D sheathing grade plywood.

1. C-grade Douglas-fir is significantly less defective on a percentage basis than C-grade Engelmann spruce but a D-grade Douglas-fir is

TABLE 17. SPECIES COMPARISONS OF KNOTS AND KNOTHOLES BY GRADE.

	Engelmann Spruce vs Douglas-Fir Significance	Douglas-Fir vs Ponderosa Pine Significance	Ponderosa Pine vs Engelmann Spruce Significance
C-GRADE			
Average Percentage Defective Area Due To Knots	.537 vs .307 ***	.307 vs .529 **	.529 vs .537 N.S.
Average Percentage Defective Area Due To Holes	.123 vs .129 N.S.	.129 vs .193 **	.193 vs .123 N.S.
Average Number of Knots	45 vs 21 ***	21 vs 42 **	42 vs 45 N.S.
Average Number of Holes	12 vs 10 N.S.	10 vs 14 *	14 vs 12 N.S.
Average Percentage Defective Surface Per Knot	.012 vs .012 N.S.	.012 vs .011 N.S.	.011 vs .012 N.S.
Average Percentage Defective Surface Per Hole	.011 vs .013 N.S.	.013 vs .012 N.S.	.012 vs .011 N.S.
Average Percentage Total Defective Surface	.672 vs .448 **	.448 vs .729 ***	.729 vs .672 N.S.
D-GRADE			
Average Percentage Defective Area Due To Knots	.656 vs .414 ***	.414 vs .970 ***	.970 vs .656 *
Average Percentage Defective Surface Due To Holes	.108 vs .305 ***	.305 vs .229 ***	.229 vs .108 ***
Average Number of Knots	26 vs 18 **	18 vs 27 ***	27 vs 26 N.S.
Average Number of Holes	5 vs 11 ***	11 vs 7 ***	7 vs 5 *
Average Percentage Defective Surface Per Knot	.027 vs .023 N.S.	.023 vs .035 ***	.035 vs .027 *
Average Percentage Defective Surface Per Hole	.021 vs .027 N.S.	.027 vs .026 N.S.	.026 vs .021 N.S.
Average Percentage Total Defective Surface	.823 vs .738 N.S.	.738 vs 1.273 ***	1.273 vs .823 ***

about the same percent defective as D-grade Engelmann spruce as far as total defective surface is concerned. This is because the D-grade Douglas-fir measured had a higher incidence of pitch and bark pockets. In both grades, the spruce had a much higher average number of knots. In C-grade there was no difference in the average number of knotholes and in D-grade the fir had a significantly higher number of holes. There was no difference in the percentage of defective surface per knot or knothole for both grades.

2. Douglas-fir appears superior to ponderosa pine in all categories that are considered measures of integrity of surface.
3. There appears to be no significant difference in knots and knotholes between C-grade ponderosa pine and Engelmann spruce and a significant difference between D-grade spruce and pine with spruce having a more integral surface where defective surface is expressed as a total of all defects. This difference is apparently due largely to knothole differences and also to the fact that the pine panels sampled had a large number of pitch and bark pockets.

With this limited study as background, a general rating of species was attempted to determine relative rankings with regard to integrity of surface. This rating is shown in Table 18.

TABLE 18. INTEGRITY OF SURFACE OF VARIOUS PLYWOOD SPECIES FOR C-AND D-GRADE VENEERS.

GRADE	Douglas-Fir	Ponderosa Pine	Engelmann Spruce
C	3*	2	2
D	3	1	3

* 1 -- Least Desirable Species 3 -- Most Desirable Species

SUMMARY AND CONCLUSIONS

In this report an attempt has been made to tabulate and quantify the technical advantages and disadvantages of plywood made from ponderosa pine and Engelmann spruce when compared to Douglas-fir, southern pine, and West Coast "whitewood" plywood. Ponderosa pine is currently classified as a Group 3 softwood plywood commercial species and Engelmann spruce is a Group 4 species although the possibility of its promotion to Group 3 appears likely. Classification of these species in their respective commercial groupings and the assigned stiffness and strength properties of the group determine to a large extent the degree to which these two species are able to compete with Douglas-fir and the southern pines (Group 1 species) and the West Coast "whitewoods" (Group 2 species). Examination of the physical properties of these two species has revealed several key areas in which they should be able to compete successfully with the major plywood species. These competitive areas are summarized below for each of the study species:

Engelmann Spruce

From the preceding examination of the mechanical and physical properties of Engelmann spruce, the following uses are the ones for which this species of plywood is most suitable and competitive: underlayment, siding, soffits, signs, billboards, boxes, crates, air cargo containers, high density overlay, tables, moveable partitions, trailer linings, and interior paneling.

In addition, an important high volume use where this plywood species can compete well is as sheathing---roof, floor, and wall. Particular niches where Engelmann spruce plywood can equal Douglas-fir, or southern pine, or equal or exceed the West Coast "whitewoods" are summarized below:

1. Based on the stiffness and strength values of the APA, a 20/0, 24/0, or 30/12 Engelmann spruce panel has the same span index as a Group 2 panel of equal thickness.
2. Tests conducted at CSU which assign higher stiffness and strength values for Engelmann spruce than are currently accepted, would allow spruce panels stamped 20/0, 24/0, 30/12, 42/20, and 48/24 to be the same thickness as Group 2 panels with identical Identification Indexes.
3. It appears that spruce roofing panels 5/16 thick over a 12-inch span meet a minimum load carrying ability of 50 psf. Also adequate for the purpose are a 1/2-inch thick panel over a 24-inch span, a 3/4-inch thick panel over a 32-inch span, and a 1-1/8-inch panel over a 48-inch span.
4. Special constructions permitted by PS 1-66 (increase in face and back veneer thicknesses and overall panel thickness) can be used to raise span indexes of Group 4 panels to Group 3 ratings. It is also technically possible to raise a Group 4 panel to Group 2 stiffness and strength by special constructions, although this is not presently permitted under PS 1-66.
5. For wall sheathing Engelmann spruce plywood can compete on an equal thickness basis with the Group 1 and Group 2 species normally used if stud spacing is confined to the usual 16- or 24-inch spans.

Ponderosa Pine

Some of the obvious uses for which ponderosa pine seems best suited are underlayment, siding, soffits, signs, billboards, boxes, crates, moveable partitions, interior paneling and kitchen cabinets. Other less easily recognized niches where ponderosa pine plywood could compete

favorably are outlined below:

1. For Identification Indexes 20/0, 24/0, 32/16, 42/20, and 48/24, and based on the stiffness and strength values assigned by the APA, a ponderosa pine panel the same thickness as a Group 2 panel may carry an identical index rating.
2. Ponderosa pine roofing panels 5/16-inch thick over a 12-inch span meet a minimum load carrying ability of 50 psf. Other thicknesses adequate for the purpose are a 1/2-inch thick panel over a 24-inch span, a 5/8-inch panel over a 32-inch span, and a 7/8-inch panel over a 48-inch span.
3. By use of special constructions, ponderosa pine panels can equal or exceed in stiffness and strength Group 2 and in some cases Group 1 panels; however, such special constructions are not permitted for Group 3 under present standards.
4. For wall sheathing ponderosa pine plywood can compete on an equal thickness basis with the Group 1 and Group 2 species normally used if stud spacing is confined to the usual 16- or 24-inch spans.

Part II - MARKET ANALYSIS

The answer to why consumers purchase some products to the exclusion of others is at best an elusive one. In some cases there are differences in products which are obvious to the consumer. In some cases the advertising industry has succeeded in creating in the minds of the consumer illusions of difference in essentially identical products. Often in the above two situations cost does not seem to be a critical factor in the consumer's choice between competing brands or products. And in still other cases a combination of cost, technical characteristics, availability, convenience, and past purchasing habits form a subtle coalition of factors which determine the sales of a particular product. This is particularly true of those products generically classified as "producers' goods." Producers' goods are those which are used in the manufacture or packaging of final consumer goods. In the manufacture and distribution of the final consumer good, producers' goods may be altered to the extent of not even being recognizable by the final consumer.

Plywood is a good example of such a producer good. The purchaser of a home, for example, may not even be aware of the extent to which plywood was used in the construction of the home, and rarely would he be aware of the species of plywood or its thickness and grade. It is generally the contractor and possibly the architect who indirectly weighs the advantages and disadvantages of cost, technical characteristics, availability and convenience in deciding between alternative species of plywood. And in many instances, past purchasing habits are more important than product characteristics in determining sales of plywood.

The above context is the one in which a market analysis for Engelmann spruce and ponderosa pine must be made. This context portends errors which may be associated with either overly optimistic or conservative estimates of future market

opportunities. In the final analysis it may well be the perspicacity of the producer which influences his sales more than any clearly defined marketing advantages.

In view of this warning, the following is a description of the kinds and size of various plywood markets and a description of the marketing channels associated with each of the markets. Next is a description of the location of the various markets and the implication of market location for freight cost advantages. This information will then be combined with the previous information on technical advantages to determine those markets for which Engelmann spruce and ponderosa pine have a potential advantage in comparison with plywood made from Douglas-fir, West Coast "whitewoods" and southern pine.

Market Categories and Distribution Channels

Market categories and distribution channels are introduced in order to get a view of where anticipated growth in plywood demand is expected and to obtain some clues as to possible strategies to enable Engelmann spruce and ponderosa pine to capture a share of this growth.

There are four major market categories for softwood plywood: residential construction, general construction, industrial, and agriculture and over-the-counter. Each category is discussed in terms of market size, distribution channels, market structure, and future demand for softwood plywood. In discussing distribution channels the various kinds of distributors have been classified into five major categories:

1. captive wholesalers (wholesale yards owned by a wood products manufacturer).
2. independent wholesalers (wholesale yards not owned by a wood products manufacturer).

3. office wholesalers (independent wholesalers who do not have a yard).
4. retail dealers.
5. mills selling directly to consumers.

Residential Construction

The residential construction market refers to plywood sold for the construction of single and multi-family houses. Residential construction refers to both conventionally built homes and off-site manufactured units. Some of the important plywood uses in this market are roof sheathing, subflooring, underlayment, wall sheathing, and siding.

Residential construction is the largest market for softwood plywood. In 1967, 52% of the softwood plywood that was produced (6,812,505 M sq. ft. 3/8" basis) was sold to this market.

Through the 1970's residential construction is expected to account for the major increase in plywood demand. An estimated 11,650 million square feet will be used in 1979 compared with 7,400 million square feet in 1970. By 1975 nearly 50% of the housing units will be factory built. An estimated 30% more plywood is used in a factory built house than in a conventionally built home. (13) The largest supplier of plywood used in residential construction is the retail dealer. In 1967, retail dealers accounted for approximately 82% (sq. ft. basis) of the sales to this market. Wholesale yards supply virtually all of the plywood to the retail dealer. Thus, the typical distribution channel for this market is the one conventionally used for lumber as well as plywood.

Manufacturer ——→ Wholesaler ——→ Retailer ——→ Contractor

Other major suppliers to contractors are independent wholesalers (11%) and captive wholesalers (5%). (18)

There are basically two reasons for the large percentage of plywood shipped

through the conventional system. First, the conventional distribution channel is an efficient means of fulfilling the needs of the residential builder. In many cases it is not feasible for mills or wholesalers to attempt to supply many small builders, so the material must be sold through retail dealers. Builders can work with local retail dealers to obtain the building materials in necessary quantities. Second, mills which produce plywood are not required to maintain a large marketing force to sell their product. Many wood product firms are fairly small operations and cannot afford to have large amounts of money invested in marketing their product.

For producers of Engelmann spruce and ponderosa pine plywood there are also some disadvantages in selling through the conventional distribution system in the residential construction market. First, the vast majority of softwood plywood is made of Douglas-fir and southern pine. Engelmann spruce and ponderosa pine are less familiar plywood species and in many cases distributors are not as conscious of selling these species. The second disadvantage is that many wholesalers will not store spruce and pine plywood in their yards and will only sell it if it can be shipped directly to the retailer or contractor.[1/] Selling of Engelmann spruce and ponderosa pine is viewed by many wholesalers as duplication of comparable Douglas-fir items. They feel this argument is particularly critical when storage space is at a premium. Lastly, the major uses for softwood plywood in residential construction are dependent upon plywood with a minimum span index. According to the standards, Engelmann spruce and ponderosa pine do not have as high span index rating as Group 1 or Group 2 species. These factors illustrate the need for producers of Engelmann spruce and ponderosa pine plywood to look for markets which are less dependent upon this strength characteristic.

1/ Personal interview with Bob Lynd, Manager, U.S. Plywood Wholesale Yard in Denver, Colorado, gave some valuable insights into the costs and benefits associated with diversification of products at wholesale yards.

If producers by-pass the conventional distribution system and sell directly to builders, they would be able to stress these physical properties other than span index which are favorable attributes. Engelmann spruce and ponderosa pine have unique features which could be brought out through personal selling. Also, loyalty between salesman and buyer was pointed out by plywood producers as important in obtaining repeat sales. This would mean that the customers would make a point of having their plywood needs satisfied by that particular mill. These advantages would be offset by the disadvantages of increased selling costs, and increased cost in servicing numerous small accounts. Personal selling by mill salesmen can only be considered for potentially large orders. Distributors of softwood plywood feel that it would not be economically feasible for mills to sell directly to contractors in the residential construction market.2/

The importance of marketing costs suggests that in the residential construction market producers of Engelmann spruce and ponderosa pine plywood will probably continue to sell primarily through the conventional distribution system.

Industrial Market

The industrial market refers to softwood plywood sold for manufactured products. There are a large number of uses for plywood in this market. Some of the larger volume uses are boxes and crates, containers, truck and railcar linings, and furniture. Manufactured housing is considered to be residential construction and not part of the industrial market.

The industrial market is the second largest of the four major marketing categories. From 1964 to 1967 the market with the greatest percentage increase in plywood used was the industrial market. The amount of softwood plywood used in 1964 was 2,066,034 M sq. ft., and the amount used in 1967 was 2,796,444 M sq. ft.

2/ Personal interviews with E. M. Andrews, E. M. Andrews Lumber Sales, Chicago, Illinois; H. Dybdal, Roberts and Dybdal, Inc., Des Moines, Iowa; and Bayless Kirtley, Red River Lumber Co., Oklahoma City.

(an increase of 26% in only four years). Further information shows that in 1967 about 60% of the plywood sold to this market was sanded. The capability of plywood to be sanded seems to be an important factor in its success in this market. (18)

Total demand for plywood in the industrial market is expected to increase by 16% through the 1970's. Demand in 1979 is estimated to be 3,500 million sq. ft. (3/8" basis). Decreases in some parts of the market are forecast, such as plywood used in products made for sale (cabinets, furniture, and fixtures) and military purchases. This decrease is expected to be offset by increases in box, crate, and pallet production. Also, plywood overlayed with metal or fiberglass will be used more in truck/trailer vans and cargo containers. (13) The industrial market is not expected to show a large increase in plywood use over the next decade, but the characteristics of Engelmann spruce and ponderosa pine plywood may make these species particularly suitable to some industrial uses and increase the share of these species relative to others used for industrial purposes.

The percentages of plywood sold to industrial markets through various distributors are as follows: (18)

1)	captive wholesalers	26%
2)	independent wholesalers	24%
3)	retail dealers	22%
4)	mill	15%
5)	office wholesalers	13%

Through the past decade there has been a trend for the proportion sold by mills directly to the user to increase. This trend has been more pronounced in the industrial market than in any of the others. (18) Retail dealers accounted for only 22 percent of the sales to industrial markets in contrast to 82 percent to residential construction.

There are several reasons for wholesalers and mills being able to sell directly to end-users. First, many industrial users are large companies who can buy relatively large quantities of plywood and have storage facilities to keep the material in good condition.[3/] Also, several of the users in the industrial market require that the supplier be able to give a degree of technical service in the use of softwood plywood. Lastly, when good service is supplied to the user as well as a good product, a degree of loyalty may be established between buyer and seller. The loyalty enables the mills and wholesalers to establish dependable buyers for their product.

General Construction

The general construction market refers to plywood which is used in construction other than residential. General construction plywood is used in construction of warehouses, bridges, storage sheds, etc. Typical plywood uses are in concrete forms, roof decking, and floor systems.

In 1967 general construction was the third largest market for softwood plywood (1,363,970 M sq. ft. 3/8" basis). This market is less than one-fifth the size of the residential construction market.

The demand for plywood in the general construction market is expected to increase by 47% in the 1970 decade. By 1979 the demand is estimated to rise to 2,650 million sq. ft. (3/8" basis). This increase will be due to increased use of plywood in concrete forms, heavy plywood decks, and trends toward prefabricated wood components for general construction purposes. (13)

By far the largest supplier of this market is the retail dealer (66%). Other major suppliers include independent wholesalers (16%) and captive wholesalers (11%). (18) In the general construction market, plywood is shipped through conventional distribution

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3/ Personal interview with Mr. John Kot, Peters and Kot, Inc., Chicago, Illinois.

channels for the same rationale that applies to residential construction.

Agriculture and Over-the-Counter Markets

For the purposes of this discussion the agriculture and over-the-counter markets for softwood plywood have been combined. The agricultural market refers to plywood used in animal sheds, barns, wagons, and other uses which are directly related to agriculture. The over-the-counter market refers to plywood used in odd jobs by "do-it-yourselfers."

Agricultural and over-the-counter market accounted for an estimated 1,984,661 M sq. ft. (3/8" basis) of plywood sales in 1967. It is estimated that these markets will increase by 35 percent during the next decade to about 2,700 million sq. ft. (3/8" basis). (13)

Retail dealers supplied virtually all of the plywood to this market (92%), with independent and captive wholesalers supplying the rest. (18) End-users in this market usually purchase very small quantities, and local retail dealers are best able to satisfy the needs of these consumers.

Conclusions

As can be seen from the following table the major growth in plywood demand during the 1970's will be in the residential construction market. A further look at the technical characteristics (later in this report) will allow some estimates of the potential success of Engelmann spruce and ponderosa pine capturing some

	Sales in Million Sq. Ft. (3/8" basis)	
	1967	1979
Residential Construction	6,813	11,650
Industrial	2,796	3,500
General Construction	1,364	2,650
Agriculture & Over-the-Counter	1,985	2,700

of this increase in the residential construction market. Though growth in the industrial markets is the smallest, it cannot be ignored because the technical characteristics of the study species suggest that these species may be particularly well adapted to some industrial uses.

Analysis of the distribution channels for plywood leads to several considerations which are relevant to successful marketing of increased amounts of Engelmann spruce and ponderosa pine plywood. In selecting distribution channels the alternatives can be summarized in an over-simplified fashion as:

A) Plywood Manufacturer ——→ User

B) Plywood Manufacturer ——→ Wholesaler ——→ User

C) Plywood Manufacturer ——→ Wholesaler ——→ Retailer ——→ User

The following considerations indicate those situations which suggest selection of one of the distribution channels in preference to the others.

1) User purchases relatively small amounts--This is the situation comparable to that found in the on-site residential construction market. It is necessary to use retailers because of impossibility of mills shipping long distances to hundreds or thousands of individual buyers.

2) User needs technical services for effective use of the product--In this situation the ideal distribution is directly from the mill or captive wholesaler. Independent wholesalers and retailers will probably lack the time, initiative and expertise to offer this service. Without the service or with improper information supplied the customer will undoubtedly be lost to a competitive product.

3) Product is new or technical advantages are not commonly recognized--Lack of knowledge of the technical characteristics describes the current status of users and retailers relative to the sale and use of Engelmann spruce and ponderosa pine. If the product is to be sold under this circumstance, then it must either be aggressively marketed or sold at a significant price differential to better-

known and accepted competitive products. Current sales of these species to the residential construction market are almost solely the result of a lower price than competitors. The only way to increase sales other than by preferential prices will be by means of aggressive marketing. This requires the development of sales forces or wholesale outlets by the manufacturer.

4) Reliability of supply and sales integrity more important than product characteristics--For some industrial markets the dollar cost of plywood represents an extremely small portion of the cost of the delivered product. For example, the case of crates for truck engine-blocks. The cost of the crate is so small relative to that of its contents that the most important factor in the sale of the plywood is the faith that the engine manufacturer has in the plywood supplier. Regularity of supply and the personality of the salesman are likely to be more important than price or plywood characteristics for these outlets. Once again direct mill sales or captive wholesalers are more likely to have these attributes than the conventional distribution channel.

Geographic Distribution and Freight Rates

In the early stages of this study, interviews with producers of Engelmann spruce and ponderosa pine plywood indicated that the major share of their sales were not in markets for which these species were uniquely suited but were in direct competition with Douglas-fir and other plywoods. To date, success in these markets has been a function of the geographic relationship between producers and consumers and because of the lighter weight of the study plywoods compared to their major competitors, Douglas-fir and southern pine. The combination of location and weight offers freight advantages which allow spruce and pine to be sold at competitive prices.

Producing and Consuming Regions

For statistical reporting purposes plywood production is generally divided into three major producing areas, Inland, Southern, and West Coast. Plywood produced in the Rocky Mountain states is included in the Inland region. Table 19 compares the Inland region's production with other producing regions.

Table 19. MAJOR PLYWOOD PRODUCING REGIONS

MILLIONS OF SQ. FT. PRODUCTION IN 1969 (3/8" BASIS)

	Total	Oregon	Wash.	Calif.	Inland	Southern
Amt.	13,700	7,200	1,800	900	900	2,900
Percent	100	52.6	13.1	6.6	6.6	21.7

ESTIMATED PRODUCTION IN 1975 (3/8" BASIS)

	Total	Oregon	Wash.	Calif.	Inland	Southern
Amt.	18,500	8,400	2,200	1,300	2,200	4,400
Percent	100	45.4	11.9	7.0	11.9	23.8

In 1969 the Inland region produced 900 million sq. ft. of softwood plywood (3/8" basis). This was 6.6% of all softwood plywood produced in the United States. The Inland region is expected to account for over 30% of the total new production by 1975. (12) This increase would mean that the Inland region would succeed the South as the fastest growing production region. By far the largest portion of the production in the Inland region is in eastern Washington, Idaho, and western Montana.

Approximately 97.2% of the Inland region's production consisted of sheathing grades of plywood (22.5% of the United States total for sheathing). Chicago and New York account for the largest percentage of the sheathing plywood sales from the Inland region. Most of the major markets are located in the East and Midwest.

Table 20. PLYWOOD SHIPMENTS TO MAJOR TRADE AREAS, 1969 (2)

Trade Area	Montezuma	ALL APA MILLS
Chicago	7,006,321	662,279,344
Cincinnati-Dayton	1,632,213	129,818,291
Cleveland	553,920	153,310,158
Columbus	812,150	70,302,160
Dallas-Fort Worth	3,358,506	262,841,411
Denver	9,171,165	155,110,105
Des Moines-Sioux City	2,781,280	139,209.941
Detroit-Toledo	1,197,014	422,303,560
El Paso	1,139,306	13,944,527
Indianapolis	2,293,439	127,590,631
Kansas City	5,460,972	208,951,195
Louisville-Evansville	2,669,201	98,514,641
Milwaukee	4,871,339	187,549,560
Minneapolis-St. Paul	281,708	283,651,253
Oklahoma City	1,669,956	52,395,950
Omaha	2,771,842	70,368,591
Phoenix	2,993,940	88,327,595
San Antonio	1,927,275	71,250,268
St. Louis	1,621,546	170,303,149
Tulsa	1,953,814	40,962,985
Wichita	1,001,386	44,750,398
TOTAL	57,168,293	3,195,177,678

Of particular importance to this study is the distribution of plywood produced in the Rocky Mountain region. It was anticipated that Rocky Mountain plywood would in general have a significant freight advantage to Midwest markets over plywood produced in the Northwest and South. To examine this, a list of twenty-one trade areas, as defined by Rand McNally, were chosen as representative of the Midwest and Rocky Mountain regions. These areas are listed in Table 20 along with a listing of the amounts of plywood shipped to each trade area by the Montezuma mill of Southwest Forest Industries at Cortez, Colorado and the other American Plywood Association mills. The Montezuma Mill is the only producer of Engelmann spruce plywood in Colorado. The 21 trade areas listed in Table 20 accounted for 92% of the plywood shipped from Montezuma Plywood. (2) The trade areas with the largest shipments from the Montezuma mill were: Denver, Chicago, Kansas City, Milwaukee, and Dallas-Fort Worth. All 21 trade areas are in the Rocky Mountain or Midwest regions. The trade areas in Table 20 appear to be the most feasible marketing areas for this particular mill. An analysis of freight differentials partially explains why these are particularly competitive markets for Rocky Mountain produced plywood.

Freight Analysis

The purpose of this analysis is to compare freight rates for Rocky Mountain producers with those faced by producers in other regions.

Through the years the producers of forest products have developed two methods of billing freight charges to their customers. The first method is to have the carrier send the bill directly to the plywood purchaser. This way the purchaser would actually pay two bills; one to the plywood producer for the actual cost of the plywood and one to the carrier for the actual cost of shipping the plywood from the mill to the consumer. This method is used to some extent today, especially

when the producer is not sure of the purchaser's credit rating. The second method, most often used, is for the mill to charge the purchaser for both the plywood and the shipping charges in one bill. The carrier will then bill the mill for the actual cost of the shipment.

Nearly all freight rates are set through a combination of four factors: (1) the distance the material will travel, (2) the weight of the shipment, (3) the type of product being shipped, and (4) the amount of material to be shipped (the number of units that will be shipped over a period of time). Freight shipments are quoted on a one hundred pound basis (hundred weight). For instance, one rate for shipping plywood by rail from Portland to Chicago is $1.77/CWT. Rates can also change with the number of pounds that are placed on each load. The above rate is based on a minimum carload of 70,000 lbs. If the car load did not weigh at least 70,000 lbs., a higher rate per one hundred pounds would be charged.

Commodity rates are tariffs which are set to handle goods shipped in large volumes with a great deal of regularity from a certain location. An example of a commodity rate for plywood is the Portland freight rate. A large amount of plywood is shipped from the Portland area, so special rates are established for this purpose. The charge for shipping a special item from Portland would carry a higher rate than a commodity item. Examples of other well known plywood commodity rates are the Spokane rate and the Crossett rate Commodity rates can be established for both truck and rail shipments. All of the rates discussed in this chapter are established commodity rates.

Table 21 shows the rates for railroad shipments from four producing regions to seven large metropolitan regions in the Midwest and the East. On the basis of these rates it appears that the producers of southern pine plywood have a

distinct freight advantage over other regions. In many cases this is true but southern pine is a heavier species than Douglas-fir and very much heavier than Engelmann spruce. The total charges listed in Table 21 are based on an 80,000-lb. load. In some cases a carload of southern pine may weigh over 100,000 lbs., compared to a carload of spruce which may weigh only 70,000 lbs.

Another point should be noted here. The rail rates from Alamosa to the different cities is the commodity rate established for Montezuma Plywood Co. The total shipping cost for Montezuma would include the cost of shipping by truck from Cortez to Alamosa. Also, there are no rail rates available for shipments from Alamosa to Denver, Oklahoma City, and Kansas City, since shipments to these cities are all made by truck.

With rail shipments Montezuma can ship as far east as the Ohio-Pennsylvania state line before it loses its freight advantage over West Coast producers. Southern producers, however, can be competitive with Rocky Mountain producers for nearly all Midwest markets. Montezuma is not able to ship large quantities of plywood into east Texas, Arkansas, Kentucky, or West Virginia. These states apparently form the southern boundary for Rocky Mountain Shipments. This is hard to determine from the tables because the cost of shipping by truck from Cortez to Alamosa is not included in the charge. It must be remembered that the rates established for Montezuma may not be representative of the entire Rocky Mountain region. There is evidence that a mill located in the Black Hills may have a cheaper rate to Chicago but it would probably be higher than Montezuma's rate to Kansas City.[4/]

4/ Personal interview with Harold Worth, Project Leader, Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colorado.

Table 21. COST OF SHIPPING PLYWOOD BY RAILROAD.

To	From Alamosa, Colo.[1] Rate/100 lb. 70,000 lb. min.	From Alamosa, Colo.[1] Total Charge 80,000 lb.	From Spokane, Wash.[2] Rate/100 lb. 70,000 lb. min.	From Spokane, Wash.[2] Total Charge 80,000 lb.	From Portland, Ore.[3] Rate/100 lb. 70,000 lb. min.	From Portland, Ore.[3] Total Charge 80,000 lb.	From Holden, La[4] Rate/100 lb. 70,000 lb. min.	From Holden, La[4] Total Charge 80,000 lb.
Denver	Use truck rate from Cortez	944	1.25	1,000	1.41	1,128	?	?
Oklahoma City	Use truck rate from Cortez	1,200	1.53	1,224	1.59	1,272	.76 (50,000) .40 (excess)	500
Kansas City	Use truck rate from Cortez	1,256	1.53	1,224	1.59	1,272	.92 (50,000) .60 (excess)	640
St. Louis	1.13	904	1.69	1,352	1.75	1,400	.67 (50,000) .48 (excess)	479
Chicago	1.16	928	1.73	1,384	1.77	1.416	.84 (60,000) .55 (excess)	614
Cleveland	1.65/1.44	1,278	1.92	1,536	1.97	1,576	1.11 (60,000) .68 (excess)	802
New York	2.01	1,785	2.01	1,785	2.01	1,785	1.39 (60,000) .85 (excess)	1,004

[1]Information supplied by Southwest Forest Industries (July 1971)

[2]Information supplied by Potlatch Forests, Inc. (July 1971)

[3]Information supplied by Weyerhaueser Company (July 1971)

[4]Information supplied by United States Plywood (July 1971)

Table 22 gives the rates for shipments by truck from the producing regions to the seven metropolitan areas. The truck rates from the Portland area were obtained through United Buckingham Freight Company while the other rates came from producing firms. Montezuma's truck shipments have an advantage over West Coast producers as far east as the Indiana-Ohio state line. The southern boundary for truck shipments is approximately the same as for rail shipments. Besides the basic factors involving transportation costs, there are some additional comparisons which can be made between shipments by rail and shipments by truck. In the case of spruce and pine plywood, the distributor seldom sees the plywood. It is shipped directly to the builder or retailer. For the most part, retailers or builders prefer to receive their plywood shipments by truck. Many times the retailer or user will not be located near a railroad. Consequently, there is the increased cost to the purchaser to offload the plywood from the rail car onto a truck, and from the truck to the retail yard or final user. This additional cost could be avoided if the mill shipped plywood by truck. Also, plywood shipped by truck usually suffers less damage than it would in a rail car. However, the advantages of truck shipment are usually not enough to offset the price differential for moderate to long hauls. The purchaser normally wants to have it shipped in the cheapest way whether by rail or by truck.

Figure 4 shows the area in which producers in southern Colorado could compete favorably with the other producing regions. This area was determined through consideration of freight rates, geographic analysis of shipments, and personal interview with knowledgeable distributors. The area outlined is not an absolute boundary for all potential Rocky Mountain producers. The exact location of a mill and the future expansion of the plywood industry could significantly alter this region.

Table 22. COST OF SHIPPING PLYWOOD BY TRUCK

To	From Alamosa, Colo.[1]		From Spokane, Wash.[2]		From Portland, Ore.[3]		From Crosset, La.[4]	
	Rate/100 lb. 40,000 lb. min.	Total Charge 80,000 lb.	Rate/100 lb. 40,000 lb. min.	Total Charge 80,000 lb.	Rate/100 lb. 40,000 lb. min.	Total Charge 80,000 lb.	Rate/100 lb. 40,000 lb. min.	Total Charge 80,000 lb.
Denver	1.18	944	1.41	1,128	1.90	1,520	-	-
Oklahoma City	1.50	1,200	1.59	1,272	2.00	1,600	.63	504
Kansas City	1.57	1,256	1.59	1,272	2.02	1,616	.74	592
St. Louis	1.75	1,400	1,75	1,400	1,96	1,568	.69	552
Chicago	1.87	1,496	1.77	1,416	1.92	1,536	1.02	816
Cleveland	Use rail rates from Alamosa	1,278	1.95	1,560	2.22	1,776	1.25	1,000
New York	Use rail rates from Alamosa	1,785	1.98	1,584	Use rail rates	1,785	2.12	1,696

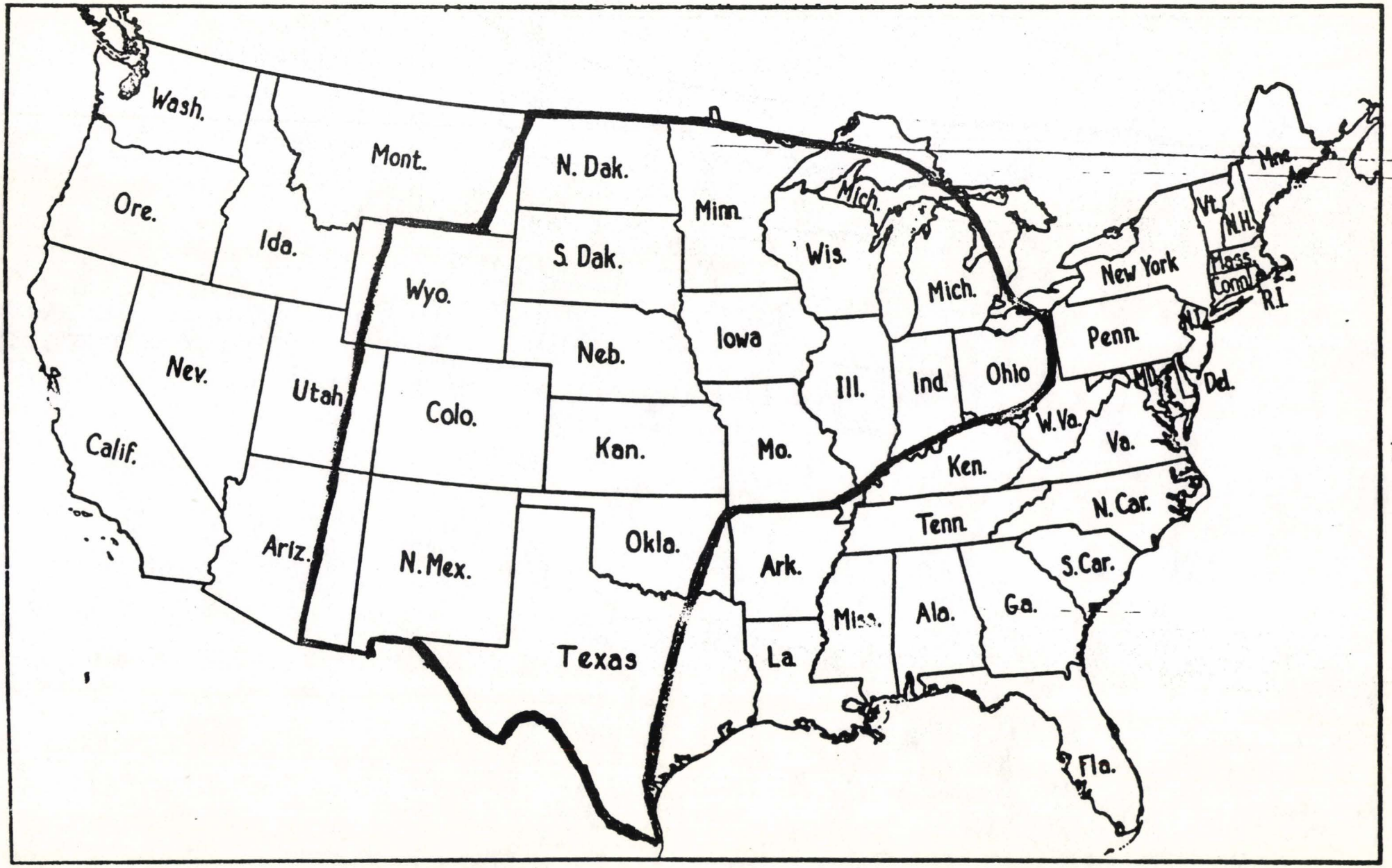
[1]Information supplied by Southwest Forest Industries.

2 " " " Potlatch Forest Industries.

3 " " " United Buckingham Freight Company.

4 " " " Georgia Pacific Corporation.

Figure 4. Area of Freight Advantage for Rocky Mountain Producers.



Market "Niches"

A detailed examination of the technical characteristics of the study species revealed several "niches" to which they were suited. To expand upon this theme of "niches" the importance of various technical characteristics for different plywood uses was compared.

Table 23 ranks the relative importance of physical properties for several plywood uses. The ratings for Table 23 were based on a scale ranging from zero to three. A zero value was given to those properties which were not important to that particular use. For example, paintability is rated zero for roof sheathing, since roof sheathing is not painted. The highest rating that a property could receive was three, such as paintability for siding. Sidings are often painted which means that paintability is a very important property for this product.

The second table, Table 24, is an ordinal comparison of these same physical properties applied to the different plywood species. These ratings are based on a scale of one to four. A one value means that the species under consideration is extremely poor for that property. For example, in comparing stiffness, Douglas-fir and southern pine have a four rating (best), while Engelmann spruce has a one rating (poorest). The stiffness rating is based on the accepted MOE values of the species. These values were taken from the Wood Handbook. Sources of comparison between species came from either the Wood Handbook or the Plywood Design Specification. Specific references for each property are given along with the definitions of each property in Appendix I.

Consideration of technical characteristics, market characteristics and market locations were then combined in order to evaluate the potential for Engelmann spruce and ponderosa pine and to suggest for which markets spruce and pine are best suited. These evaluations follow and are listed according to major market categories.

Table 23. RELATIVE IMPORTANCE OF PHYSICAL PROPERTIES IN PLYWOOD USES

PHYSICAL PROPERTY	Roof Sheathing	Subflooring	Underlayment	Combination Floor	Wall Sheathings
Stiffness	3	3	0	3	3
Bending Strength	2	3	0	3	2
Rigidity	2	2	0	2	2
Light Weight	2	1	1	3	1
Thermal Insulation	2	1	1	1	2
Machining	0	0	2	2	0
Fastener	2	2	2	2	2
Light Color	0	0	0	0	0
Integrity of Surface	1	1	3	3	1
Surface Hardness	0	0	3	3	0
Dimensional Stability	2	2	3	3	2
Weathering	0	0	0	0	0
Paintability	0	0	0	0	0
Gluability	0	2	3	3	0
Appearance	0	0	0	0	0
Acoustical Insulation	1	1	1	1	2

0 = Not a consideration
1 = Of Some Importance
2 = Important
3 = Very Important

Table 23 Continued. RELATIVE IMPORTANCE OF PHYSICAL PROPERTIES IN PLYWOOD USES.

PHYSICAL PROPERTY	Siding	Combination Siding	Lining of Vans and Rail Cars	Boxes
Stiffness	1	3	1	3
Bending Strength	1	2	1	3
Rigidity	1	2	1	3
Light Weight	1	1	2	2
Thermal Insulation	2	2	2	1
Machining	2	2	1	2
Fastener	2	2	3	3
Light color	2	2	0	2
Integrity of Surface	3	3	2	1
Surface Hardness	3	3	3	2
Dimensional Stability	3	3	2	1
Weathering	3	3	1	2
Paintability	3	3	0	1
Gluability	1	1	1	0
Appearance	3	3	1	2
Acoustical Insulation	2	2	1	0

0 = Not a Consideration
1 = Of Some Importance
2 = Important
3 = Very Important

Table 23 Continued. RELATIVE IMPORTANCE OF PHYSICAL PROPERTIES IN PLYWOOD USES.

PHYSICAL PROPERTY	Pallets	Air Cargo Containers
Stiffness	3	3
Bending Strength	3	3
Rigidity	3	2
Light Weight	1	3
Thermal Insulation	0	1
Machining	1	2
Fastener	3	3
Light Color	1	2
Integrity of Surface	0	1
Surface Hardness	3	2
Dimensional Stability	1	1
Weathering	2	2
Paintability	0	1
Gluability	0	0
Appearance	0	1
Acoustical Insulation	0	0

0 = Not a Consideration
1 = Of Some Importance
2 = Important
3 = Very Important

Table 24. COMPARISON OF PHYSICAL PROPERTIES OF VARIOUS PLYWOOD SPECIES

PHYSICAL PROPERTY		Douglas Fir	Western Hemlock	White Fir	Southern Pine	Ponderosa Pine	Engelmann Spruce
Stiffness		4	3	3	4	2	1
Bending Strength		4	2	2	4	2	1
Rigidity		4	2	2	4	2	1
Light Weight		1	2	3	1	2	4
Thermal Insulation		1	2	3	1	2	4
Machining		1	3	3	1	4	3
Fastener		4	3	2	4	3	1
Light Color		2	2	4	2	2	4
Integrity of Surface	C	4	3	4	2	2	3
	D	4	3	4	2	2	4
Surface Hardness		4	3	2	4	2	1
Dimensional Stability		4	4	4	4	4	4
Weathering		3	4	3	3	4	4
Paintability		3	4	4	3	4	4
Gluability		3	3	4	3	3	4
Appearance		Subjective	Subjective	Subjective	Subjective	Subjective	Subjective
Acoustical Insulation		3	3	3	3	3	3

An ordinal rating of species from 1 (least suitable species) to 4 (most suitable species).

Residential Construction

The end-uses considered in the residential construction market were roof sheathing, subflooring, underlayment, combination flooring, wall sheathing, siding, and combination siding. These uses represent approximately 90% of the plywood sold in the residential construction market in 1968.(19) Most of these uses are subject to local building codes which establish the minimum physical requirements for a particular use. This is important in light of the fact that local building codes may be almost unreasonably demanding in strength requirements for plywood. Each use is discussed in light of these requirements and particular market characteristics of the end-use.

Roof Sheathing

The most critical property for roof sheathing is stiffness. Other properties considered to be slightly less important for this use were bending strength, light weight, thermal insulation, nail holding capacity, and dimensional stability. Douglas-fir and southern pine are rated highest in strength properties and on this basis must be considered most suitable for roof sheathing. The next most suitable is Western hemlock and white fir, with Engelmann spruce and ponderosa pine the least suitable on a relative basis.

The standards and specifications for roof sheathing give the minimum strengths required at a given span. In many cases the study species are able to just satisfy these minimums while Group 1 and/or Group 2 species are substantially above the minimums.

Examples of the "niches" where ponderosa pine and Engelmann spruce satisfy minimum specification requirements were found in the conclusions to the section on Technical Advantages and Disadvantages.

In 1970 an estimated 2,440 million sq. ft. of plywood (3/8" basis) was used for roof sheathing, primarily in residential construction. On a square foot basis plywood's market share for roof sheathing is approximately 84%. The major competing material is lumber, but plywood is continuing to displace lumber for this use. The volume of roof sheathing used per unit should remain fairly stable, but the anticipated increase in the number of housing starts will assure that this use for plywood will expand.

An estimated two-thirds of the plywood used for roof sheathing was 1/2" and one-third was 3/8". Estimates of roof spacing show that 24" spacing of roof trusses is used about two-thirds of the time and 16" spacing one-third of the time. (19) From this information a conclusion can be drawn that 1/2" plywood is usually used for 24" spacing. The construction practice of "over building," combined with the information of accepted standards reveals that spruce and pine plywood could be used interchangeably with Douglas-fir and southern pine on nearly all of the roof systems used today. Hence roof sheathing is an end-use area where Engelmann spruce and ponderosa pine could be used. To compete in this market, however,will require a price lower than Douglas-fir. If milling costs for the Rocky Mountain produced plywoods are comparable to Douglas-fir, then a price differential can probably be offered to purchasers because of savings in freight rates.

Subflooring

The most critical properties for subflooring are stiffness and bending strength. Rigidity, nail holding ability, dimensional stability and gluability were also rated as important. On the basis of physical properties both roof sheathing and subflooring have the same order of species suitability: Douglas-fir, southern pine, Western hemlock, white fir, ponderosa pine, and Engelmann spruce.

The same concept of satisfying minimum requirements applies in subflooring as was discussed with regard to roof sheathing; therefore, Douglas-fir and the southern pines seem to be the best suited for this application. However, there are again particular "niches" where the study species can be used interchangeably with Group 2 ~~those~~ species.

Span

12 Ponderosa pine and Engelmann spruce panels, the same thickness as Group 2 panels, satisfy the minimum requirements for this span.

16 Ponderosa pine, the same thickness as Group 2 panels, satisfy the minimum requirements for this span

20 Ponderosa pine, the same thickness as Group 2 panels, satisfy the minimum requirements for this span.

In 1968 an estimated 1,410 MM square feet (3/8" basis) of plywood was used for subflooring. The major competitors for this use were lumber and concrete slabs. Plywood's share of the single-family floor market increased from 35% in 1962 to 56% in 1968. Its market share is expected to continue to increase. An estimated 96% of the floor systems use a joist spacing of 16 inches on center. Standard grade was used 97% of the time in single-family housing, and 88% in multi-family housing. The thicknesses used most often were 1/2" (63%) and 5/8" (25%). Since 1962 the proportion of overbuilt floor systems has declined. (19)

In order for a plywood species to be accepted in the flooring market, it must satisfy a 16" span index and not exceed a thickness of 5/8". Ponderosa pine is able to meet these specifications. According to existing standards a panel with face and back of Group 3 species can be used for 16" floor spacing if it is 5/8" thick. (6) Since approximately 25% of the plywood used for subflooring is

5/8" thick, subflooring could possibly be a market for ponderosa pine plywood. In many cases producers would be able to use pine on the faces and spruce as the core material.

Underlayment

Physical properties of importance for underlayment are integrity of surface, surface hardness, dimensional stability and gluability. Of slightly lesser importance are properties of machining and fastener holding. Integrity of surface is important, therefore, the face of the plywood must be free of voids.

This means that a C grade face must be plugged. Since floor coverings are applied directly to the underlayment, another property not considered in the ratings, but of some importance, is grain contrast; that is, the contrast in hardness between early and late wood which shows through thin flexible floor covering. The study species when compared to Douglas-fir and southern pine should reduce this telegraphing effect. On the basis of physical properties the species which were considered to be most suitable for underlayment were white fir, Western hemlock, Engelmann spruce, and Douglas-fir.

It appears that nearly any plywood species could satisfy the minimum stiffness and strength requirements for underlayment. The least desirable species for this use would be southern pine and ponderosa pine because of the large number of knotholes present in C grade veneers of these species. However, ponderosa pine from some regions may have smaller and fewer knots than are typical for veneer made from southwestern ponderosa pine.

Marketing information on plywood used for underlayment indicates that approximately 421 MM sq. ft. (3/8" basis) of softwood plywood was used for this purpose in 1968. The most common thicknesses used in multi-family construction were 1/2" (20%), and 5/8" (66%). This is compared with single-family construction, in which the most common grades are C-D Plugged (11%), and

Underlayment (77%). The most common thicknesses in single-family units are 5/8" (69%), 1/2" (11%), 3/8" (7%), and 1/4" (11%).

Although particleboard is continuing to capture a greater share of the underlayment market, the amount of plywood underlayment is expected to remain about the same through the 1970's, due to increases in housing starts. (2)

Combination Floor

Combination floor is often referred to as a single layer floor system because it is one sheet of plywood which serves a dual function as subfloor and underlayment. The properties which were considered very important were stiffness, bending strength, light weight, integrity of surface, surface hardness, and gluability. Douglas-fir was rated the best species because it had a combination of strength and surface integrity.

The American Plywood Association has established recommendations for single floor construction. These recommendations are summarized in Table 25.

Table 25. PANEL THICKNESS RECOMMENDED FOR SINGLE LAYER FLOOR (5)

SPECIES GROUP NUMBER	SPAN IN INCHES		
	16	20	24
1	1/2	5/8	3/4
2 and 3	5/8	3/4	7/8
4	3/4	7/8	1

Table 25 shows that for each span a Group 2 and a Group 3 species must be 1/8" thicker than a Group 1 panel, and a Group 4 species must be 1/8" thicker than a Group 2 or 3 panel. (5)

In 1968 approximately 756 million sq. ft. (3/8" basis) of softwood plywood were used for the combination subfloor/underlayment product. In single-family

houses the major grades used were Underlayment (48%), C-D Plugged (22%), 2.4.1 grade (15%), and Standard (11%). The major thicknesses used in this use were 5/8" (37%), 3/4" (37%) and 1-1/8" (18%). In multi-family homes the primary grades were Standard (33%), Underlayment (33%) and C-D Plugged (25%). Again, well over 90% of the floor joist spacing was 16" on center. (19)

There has been an increasing use of single layer floor construction using softwood plywood. One reason for this is that manufactured houses use primarily one layer floor systems. The major competitors are concrete slabs and particleboard.

For single floor construction 5/8" ponderosa pine can be used over 16" spans. Engelmann spruce can be used with a thickness of 3/4" over a 16" span. The combined percentage of the single floor systems made from these two thicknesses was 74%, and this is virtually all over 16" spans. (19) It must be emphasized that spruce and pine or combinations of spruce and pine could satisfy 74% of the market for single layer floors.

Wall Sheathing

The physical property rated most important for wall sheathing was stiffness. Rated slightly less important were bending strength, rigidity, thermal insulating ability, fastener holding, dimensional stability and acoustical insulation. Again Douglas-fir and southern pine would be considered the most suitable species if only physical properties are considered.

Specifications for wall sheathing are established on the basis of minimum requirements for specific stud spacings. Some definite niches exist for Engelmann spruce and ponderosa pine plywood despite their apparent inferiority based on the rating of basic physical properties. Tables of the American Plywood Association's Plywood Construction Guide list panel thicknesses, identification

i ndexes, and stud spacings that identify some definite marketing opportunities.

For a 16" stud spacing the minimum recommended panel thickness is 5/16". Any panel that is 5/16" thick and has at least a 12/0 span index will qualify for use. A 5/16" Douglas-fir panel would carry an index of 20/0, ponderosa pine an index of 16/0, and spruce an index of 12/0. A builder could satisfy the standards by using the same thickness of any of the above species. A parallel relationship also holds for stud spacing of 24". (5)

Softwood plywood has about 15% (240 million sq. ft., 3/8" basis) of the wall sheathing market for single-family homes, and 4% (16 million sq. ft., 3/8" basis) of the wall sheathing market for multi-family units. Virtually all plywood used for this purpose was Standard grade and most of it was bonded with exterior glue. The primary thickness used was 1/2". Nearly all of the stud spacings were 16" on center. (19) The minimum recommended thickness for a stud spacing of 16" on center is 5/16". (5) This indicates that there is a considerable amount of over construction on the part of the builders.

Spruce and pine could meet the minimum specification requirements for wall sheathing on equal terms with other species, and this should provide a good marketing opportunity. In the future, however, there may be a decline in the amount of plywood wall sheathing used. This is mainly due to the increased popularity of single wall construction (one material which serves as both sheathing and siding).

Siding

The most important properties for siding were integrity of surface, surface hardness, dimensional stability, weathering, paintability, and appearance. White-fir, Douglas-fir, spruce and hemlock can be rated as the most acceptable species. Appearance, which is probably the most important property, is almost

entirely dependent on individual tastes. Consequently, an adequate rating system for appearance could not be established. It may be possible to develop a siding product out of ponderosa pine or Engelmann spruce by taking advantage of the rustic appearance of the species.

The three basic types of siding which are recognized by the American Plywood Association are: (1) lap siding (24 inch strips which are installed in a horizontal direction and are overlapping), (2) bevel siding (24 inch wide strips which are tapered to give an overlapping appearance), (3) panel siding (full panels of siding placed vertically over the wall sheathing). The minimum recommended thicknesses are 5/16" and 3/8". These sidings may have a sanded veneer face for staining, a medium density overlay face (MDO grade) for painting, or a textured surface (303 siding grade) for staining. They may have in addition to any of these surfaces vertical grooves (T1-11 grade) to resemble a board on board lumber siding. (5) Any commercial softwood species would be technically acceptable for siding material, subject to appropriate surface treatment for the weather exposure.

Approximately 271 million sq. ft. (3/8" basis) of softwood plywood was used for siding material in 1968. This information was not broken down between siding which is placed over a sheathing material and siding which is applied directly to the studs and serves as both the sheathing and siding of the house. The most common thicknesses were 3/8" (56%) and 5/8" (39%). All of this product is bonded with exterior glue.

The major competitors for the siding market are brick, lumber (primarily redwood and Western Red cedar), aluminum, stucco, and hardboard. There seems to be a decline in the amount of conventional plywood siding material used because of the increase in use of the single layer wall system where the siding also serves as a sheathing material. (23)

Combination Siding

Combination siding combines the important technical functions of both siding and sheathing. Engelmann spruce and ponderosa pine were rated slightly lower than other species because they do not have strength values as high as the other species. However, there are no standards or specifications which would restrict the use of the Engelmann spruce and ponderosa pine when they are used as siding in single wall construction. The American Plywood Association indicates that any Exterior plywood siding grade can be applied directly to the studs. For stud spacing of 16" the recommended thickness is 3/8". (5)

By 1972 an estimated 700 million sq. ft. (3/8" basis) of softwood plywood will be used for siding material. This is compared with 271 million sq. ft. used in 1968. The major reason for this increase is because a panel of plywood can be used as both a sheathing and siding material at the same time. This concept is widely used in modular homes. However, there is a problem of gaining building code acceptance of the single wall system in some areas. Also, many builders still believe that a separate sheathing material is necessary. These attitudes should change as the public becomes more aware of the technical acceptability of this system. (23)

The ability of Engelmann spruce and ponderosa pine to penetrate this market depends largely on the ingenuity of producers in developing attractive siding products. Research is needed on finishes that can enhance the rustic appearance of the wood and make it attractive to the consumer. This market is growing rapidly and holds great possibility for producers of Engelmann spruce and ponderosa pine if attractive siding products can be developed.

C onclusions to Residential Construction Uses

In the residential construction market the uses which would most likely result in sales of Engelmann spruce and ponderosa pine are roof sheathing, underlayment, wall sheathing, and combination siding. Spruce and pine are at a slight disadvantage in the roof sheathing market because they do not have as high a span index rating as Group 1 species. However, with the present practice of "over building" both Engelmann spruce and ponderosa pine could satisfy the technical requirements as well as a Group 1 panel of the same thickness. Spruce and pine plywood can satisfy the technical specifications for underlayment material as well as any other plywood species. However, much will depend upon the economic feasibility of making C plugged plywood from C grade veneer. Engelmann spruce and ponderosa pine are as suitable for wall sheathing as any other species. Combination siding and sheathing is a growing market for softwood plywood and Engelmann spruce and ponderosa pine are as technically suitable for this use as any of the other softwoods being considered. Sales in this market will largely depend on a firm's ability to create an attractive product which can withstand various weather conditions. These end-uses appear to be the most suitable markets for spruce and pine plywood in the residential construction field.

Industrial Uses

The uses considered in the industrial market were van interiors, boxes and crates, pallets, and air cargo containers. These uses represent approximately 23% of the industrial market. There are many widely diverse end-uses for softwood plywood in the industrial market, each requiring a unique set of physical properties. Unlike the residential construction market, characteristics other than span index are important in many industrial uses of softwood plywood.

For example, in containers the weight of a material can be a significant factor. The unique physical characteristics of Engelmann spruce and ponderosa pine can be better taken advantage of in the industrial market than any of the others. One disadvantage for spruce and pine in this market is that many of the uses require a face veneer of A or B grade. (19) Virtually all spruce and pine plywood now produced has a C grade face. The uses discussed here are important but diversified uses which are representative of the variety of products in the industrial market.

Van Interiors

The important physical properties for van interiors are fastener holding and surface hardness. All plywoods were rated in approximately the same range. Douglas-fir could be rated somewhat higher than the others because of its hardness and surface integrity; veneer surface integrity is only applicable if C-D plywood is being used. If the plywood grades used have B or A faces, the study ratings for surface integrity are not meaningful.

In the course of this study no specifications were found to be in effect for interior liners. Manufacturing companies may establish their own standards for using plywood.

In 1968 an estimated 98 million sq. ft. (3/8" basis) of softwood plywood was used in truck trailer vans. The plywood was usually used as a liner on the inside walls, and in some cases as a floor material. The grades used most often were A-D, B-C, and A-C. The most common thicknesses were 1/4", 3/4" and 3/8". (19)

A new material which is being used more often in this market is plywood overlaid with fiberglass or metal. This material is also important in the construction of marine cargo containers. Spruce and pine plywood is an excellent substrate for these overlays.

It would be difficult to sell spruce or pine without overlays as an interior lining material because of the high grade veneers which are required. There is however, a possibility that the study species could be used as a sheathing material inside the metal exterior of a trailer van. Some spruce and pine plywood is used for this purpose now. The only advantage of using spruce or pine would be the lighter weight. Also the market size would be quite small.

Boxes and Crates

The properties considered to be most important for boxes and crates were stiffness, bending strength, rigidity, and fastener holding. Douglas-fir and southern pine were considered most suitable because of their strength properties. Ponderosa pine and spruce are not rated as high in these properties but are of considerably lighter weight than Douglas-fir and southern pine.

There are numerous manuals and specifications on box and crate design. One of the most widely used was published by the U. S. Forest Service, Forest Products Laboratory. (38) This manual classifies the species by their properties. Spruce and ponderosa pine are classified as Group 1 (they are light in weight, do not split when nailed, moderate nail holding capacity, and fairly soft). The other species are classified as Group II (heavier woods, greater nail holding capacity, and they split more easily than Group 1). The design specifications mentioned specify which group should be used in certain constructions. The purpose of classifying these species is to help the box manufacturer decide which species to use.

In 1968 about 364 million sq. ft. (3/8" basis) of softwood plywood was used in construction of boxes and crates. This amounts to about 12% of the total material used. The other 88% is made up of lumber. The most common

grade of plywood used was Standard. The thicknesses used most often were 1/4" and 1/2". (19)

Nearly three-fourths of the plywood was used by companies who make boxes and crates for their own use. Industries which were the most important users of plywood in containers were:

Machinery
Packing and Crating
Lumber and Wood Products
Electrical Machinery Manufacturers
Transportation Equipment Manufacturers

The main reason for using plywood is because it is stronger and more durable than lumber in this use.

Manufacturers of spruce and pine plywood may be in a good position to supply this market. Spruce and pine will in many cases have the strength to be used in box construction and have the advantage of being lighter in weight than Douglas-fir or southern pine. Plywood seems to be gaining a slightly larger share of the box and crate market. This increase is quite slow because box and crating lumber is a much cheaper material than plywood. Also, several large box manufacturers depend on this market as an outlet for timberlands and sawmills which they own.

Pallets

The properties considered to be most important for manufacture of pallets were stiffness, bending strength, rigidity, fastener holding, and surface hardness. Douglas-fir and southern pine were rated as the best species because of their superior strength properties. Engelmann spruce is the lowest rated species for these properties.

In 1968 an estimated 300 million square feet (3/8" basis) of softwood plywood was used in the manufacture of pallets and pallet bins. Approximately

100 million sq. ft. were used in pallets for agricultural purposes and 200 million sq. ft. were used in pallets by industrial manufacturers. In most cases the users bought their pallets from pallet producers. Only a very minor portion of the pallets are made from plywood. One reason for this is the difference in cost. An oak board pallet costs about one-third as much as a plywood pallet of comparable size and strength.

In some cases, such as grocery stores, produce may be displayed in pallet bins. For this kind of use a higher grade of plywood such as A-C, or A-D will be used. (23) For most industrial pallets and pallet bins, however, there is no real emphasis on appearance and Standard grade is used.

Engelmann spruce and ponderosa pine can be used in the manufacture of pallets. However, the other species studied have more suitable physical properties. Also, there is a great deal of price competition from lumber. Pallets and pallet bins do not appear to be a particularly good market for spruce and pine plywood.

Air Cargo Containers

Most important properties of plywood for air cargo containers are stiffness, bending strength, light weight, and fastener holding. Light weight is the most critical factor for this use. On this basis, Engelmann spruce and ponderosa pine must be rated as the most suitable species.

The Air Transport Association of America (ATA) and the International Air Transport Association (IATA) are the two agencies which register containers. For domestic shipments these two agencies recognize four basic sizes: A, B, C, and D. The D container is most popular and versatile, and is also the smallest. There are seventeen internationally recognized types of containers. Weight limit restrictions are 1 lb. per cubic foot for domestic containers and 1-1/2 lb. per cubic foot for international containers. If a container weighs more than

this, the shipper must pay for the excess as though it were part of his cargo. (36)

The low density softwoods can meet this 1-1/2 lb. per cubic foot requirement. Many of the plywood containers that were tried did not hold up well. This may mean that strong metal or fiberglass overlays will have to be used in conjunction with plywood.

At present, use of air cargo containers is limited. The future, however, seems to be very good. It is predicted that loading and unloading large planes with anything approaching acceptable efficiency will require use of unit containers. At present there is no one material which is considered ideal for air cargo containers. The material used most often in the D size containers is fiberboard. Fiberboard's shortcomings are that it does not wear very well and it doesn't hold up well when it gets wet. Currently, plywood is used as a flooring material in containers of nearly all sizes. It may be possible for plywood overlaid with fiberglass to gain a good share of this market.

Two factors will be necessary for plywood to achieve much success in the air container market. First, an inexpensive return rate must be established for a knocked-down container. Second, the container must weigh no more than 1-1/2 lb. per cubic foot. Engelmann spruce, having one of the highest strength/weight ratios, is in a good position to take advantage of this new and expanding market.

Conclusions to Industrial Uses

In the industrial market the uses which would most likely result in sales of Engelmann spruce and ponderosa pine plywood are: boxes and crates, pallets and pallet bins, and air cargo containers. Spruce and pine will in many cases possess the strength characteristics needed for use in boxes and crates. They also are lighter weight than competing species which could mean savings to the users from cheaper transportation costs. Softwood plywood in construction of

p allets and pallet bins is usually C-D grade. Spruce and pine can be used in pallets but the other species would be more suitable for this purpose. Air cargo containers is a prospective market for Engelmann spruce plywood. Spruce's light weight enables it to better meet the trade specifications than other plywood species. This is expected to be a growing opportunity for marketing spruce and pine plywood, particularly in combination with overlays of metal or fiberglass.

Industrial uses offer the greatest opportunity to take advantage of particular characteristics of spruce and pine plywood. In addition to the specific uses mentioned, there will undoubtedly arise several new uses for these species on which an aggressive sales program will be able to capitalize. This market also offers an opportunity for a competitive position other than through price competition such as in the residential construction market.

LITERATURE CITED

1. American Institute of Timber Construction. 1966. Timber Construction Manual. First Edition. John Wiley and Sons, Inc., New York.

2. American Plywood Association. Geographic Analysis of Plywood Shipments, Fourth Quarter, 1969.

3. American Plywood Association. 1970. Long-term Forecast/ Plywood Demand/ 1970--79. July, 1970.

4. _____. 1966. Plywood Design Specification. Tacoma, Washington. 15 pp.

5. _____. 1970. Plywood Construction Guide for Residential Building. Tacoma, Washington. 29 pp.

6. _____. 1968. Plywood Construction Systems for Commercial and Industrial Buildings. Tacoma, Washington. 56 pp.

7. _____. Personal letter to Dr. F. F. Wangaard, Colorado State University, from J. M. Carney, Head, Engineering Service, (with a September 15, 1966, APA letter as an enclosure) dated February 1, 1971.

8. _____. Personal letter to Dr. F. F. Wangaard, Colorado State University, from T. E. Batey, Jr., Product Research Department, dated February 4, 1971.

9. _____. Personal letter to Dr. F. F. Wangaard, Colorado State University, from T. E. Batey, Jr., Product Research Department, dated September 16, 1970.

10. American Society for Testing and Materials. 1966. Standard Methods of Testing Veneer, Plywood, and Other Glued Veneer Construction. ASTM Designation D805-63.

11. _____. 1970. Standard Methods for Establishing Clear Wood Strength Values. ASTM Designation D2555-70.

12. Anderson, Robert G. Regional Production and Distribution Patterns of the Softwood Plywood Industry, American Plywood Association, Market Research Report, November, 1970.

13. _____. Ten Year Forecast of Plywood Demand 1970-1979. American Plywood Association, July, 1970.

14. Barger, Roland & Herbert Fleischer. 1964. New Products from Low Grade Ponderosa Pine Timber. U. S. Forest Service Research Paper RM-10.

15. Dorsett, R. 1966. Central Rockies Provide Plywood Marketing Potential. Forest Products Journal 16(12): 27-30.

16. Fassnacht, D. L. 1964. The Story Behind the New Southern Pine Plywood Industry. Forest Products Journal 14(1): 21-22.

17. _____. 1965. Southern Pine Plywood. Southern Lumberman 210(2616): 15-16.

18. Felch, David B. 1968. Plywood Distribution Trends 1962, 1964, and 1967. American Plywood Association.

19. _____. 1970. Major End-Use Markets for Softwood Plywood. American Plywood Association.

20. Fleischer, H. O. & John F. Lutz. 1963. Technical Considerations for Manufacturing Southern Pine Plywood. Forest Products Journal 13(1): 39-42.

21. Guttenberg, Sam & Clyde Fasick. 1968. Economics of Plywood Production in the Southern Pine Region. Forest Products Journal 18(5): 43-47.

22. Haskell, H. H., W. M. Blair, and William Donaldson. 1966. Progress and Problems in the Southern Pine Plywood Industry. Forest Products Journal 16(4): 19-24.

23. Hilferty, James P. 1971. Plywood End-Use Marketing Profiles 1970-1972. American Plywood Association, Market Research Report.

24. Holley, D. L., Jr. 1969. Potential Growth of the Southern Pine Plywood Industry. U. S. Forest Service Research Paper. SO-41.

25. International Conference of Building Officials. 1970. Uniform Building Code, Volume I. Pasadena, California. 651 pp.

26. Lambert, H. 1970. Industry Marks Second Best Year Despite Gyrations of Market. Forest Industries 97(1): 34.

27. MacLean, J. D. 1941. Thermal Conductivity of Wood. Heating, Piping, and Air Conditioning 13: 380-391.

28. National Bureau of Standards. 1966. U. S. Product Standard PS 1-66. Softwood Plywood - Construction and Industrial, with Amendment #6. Dated June 8, 1970.

29. Norman, W. C. 1964. The Future of the New Southern Pine Plywood Industry. Forest Products Journal 14(1): 23-24.

30. Pennington, Earl R. 1970. Fiberglass Reinforced Plastic Plywood. A Growing Market for the Plywood Industry. American Plywood Association, Market Research Report.

31. Perkins, N. S. 1962. Plywood Properties, Design and Construction. Douglas Fir Plywood Association. Tacoma, Washington. 132 pp.

32. Perry, T. D. 1948. Modern Plywood. Second Edition, Pitman Publishing Corporation. New York.

33. Row, Clark. 1963. Problems in Promoting New Wood Products. Southern Lumberman 207(2585): 91-93.

34. Schuldt, J. P. and H. E. Troxell. 1970. Evaluation of Full-sized Engelmann Spruce Plywood Panels. Report #3. Prepared for Montezuma Plywood Company. 22 pp.

35. Troxell, H. E. and F. F. Wangaard. 1969. Why Species Group 4 for Engelmann Spruce Plywood? Department of Forest and Wood Sciences, Colorado State University.

36. Uppendahl, Donald E. 1968. The Development of Air Cargo Containers. American Plywood Association, Research Paper.

37. U.S.D.A. Forest Products Laboratory. 1955. Wood Handbook, Agriculture Handbook #72.

38. U. S. Department of Agriculture. 1941. Wood Crate Design Manual. Washington, D. C. Government Printing Office.

39. U. S. Department of Commerce. 1971. Current Industrial Reports. Softwood Plywood, 1970. June 29, 1971.

40. USFS Resource Bul. INT-7: 1967. Timber Resources and Industries in the Rocky Mountain states.

41. Wangaard, F. F. 1943. The Effect of Wood Structure upon Heat Conductivity. Transactions of the American Society of Mechanical Engineers, Volume 65 (2): 127-135.

42. _____. 1961. Heat Transmissivity of Southern Pine Wood, Plywood, Fiberboard, and Particleboard. Wood Science 2(1): 54-60.

43. Wilson, T. R. C. 1932. Strength-moisture Relations for Wood. U.S.D.A. Technical Bulletin #282. 88 pp.

44. Wood, L. W. 1951. Relation of the Strength of Wood to Duration of Load. U.S.D.A. Forest Products Laboratory Report #R1916.

45. Yerkes, Vern, Duane Lloyd, and Gordon Lewis. 1968. Softwood Plywood Production and Distribution. 1965. U. S. Forest Service Research Paper RM-34.

APPENDIX I

DEFINITIONS OF USES

Roof Sheathing: the skin over the roof rafters. It would not be directly exposed to the outside because materials like roofing paper and shingles would cover it.

Subflooring: the floor layer which is placed over the joists. It is the material which gives stability to the floor.

Underlayment: the second layer of the floor which covers the subfloor. The finished floor layer, such as tile or carpet, covers the underlayment.

Combination Floor: a combination of both the subfloor and the underlayment. It is a single piece of plywood which has the properties of both the subfloor and the underlayment.

Wall Sheathing: the skin on the wall. It is outside of the studs and inside of the siding.

Siding: refers to Exterior siding. It would be placed over the wall sheathing and would be fully exposed to the weather. Not a combination of sheathing and siding.

Combination Sheathing and Siding: would be placed directly onto the studs and would serve as the exterior siding. Examples are sturdiwall construction, or stressed skin.

Interior linings of Vans and Railcars: refers to the plywood which is used as a lining on the walls of trailer vans and box cars.

Pallet Bins: refers to containers with sides that are made to be transported by fork lift. Sides and bottom could be made of plywood.

Air Cargo Containers: are containers which are used to ship material by aircraft. These are reusable containers which will need to conform to specifications established by FAA.

Water Cargo Containers: refers to containers used on large ships for transporting cargo. They would have to conform to specifications and would be used repeatedly.

Cabinets-Exterior: refers to plywood which is overlayed with some material and used as doors, sides, or faces of a cabinet.

Cabinets-Interior: refers to plywood used as backs, uppers, shelves, or bottoms. This plywood would be painted in nearly all cases.

Boxes: refers to most forms of crating and packaging which use plywood. Examples are packages for auto engines, furnaces, etc. There is no restriction on size. Includes disposable boxes.

DEFINITION OF PHYSICAL PROPERTIES

Stiffness: the ability of a material to resist deformation when an external force is applied. Modulus of Elasticity was used as the basis for comparing the stiffness property between species. Page 70, Wood Handbook.

Bending Strength: the ability of a beam to support a slowly applied load over a short period of time. Modulus of rupture was used to compare the bending strength property between species. Page 70, Wood Handbook.

Rigidity: the ability of a panel to resist deformation "out-of-square." Shear values through the thickness of the panel. Rigidity as a diaphragm. From Plywood Design Specification.

Light Weight: a measure of the relative weights of the different panels. Specific gravity was used as the basis of comparison. Page 70, Wood Handbook.

Thermal Insulation: a measure of how well a material will restrict the flow of heat. Specific gravity was used as the basis for comparison. Page 70, Wood Handbook.

Machining: a measure of the ease with which various woods can be worked with hand tools. This includes such things as sanding, cutting, grooving, etc. The comparison was made in a table on page 62, Wood Handbook.

Fastener: the ability of the material to hold different types of fasteners such as nails or screws. The comparisons were based on specific gravity. Page 70, Wood Handbook.

Light Color: refers to the color of the growth rings. Well defined growth rings as in Douglas-fir will have a veneer with pronounced grain. Also refers to the color shade of the wood. Comparisons were made from table on page 40 of the Wood Handbook.

Integrity of Surface: a measure of the amount of defective area due to knots and knotholes in C and D grades. Comparisons were made from author's own study.

Surface Hardness: the resistnace of the wood to wearing, marring, and puncture. Comparisons were made on the basis of hardness properties. Page 70, Wood Handbook.

Dimensional Stability: a measure of how well a material can maintain the same dimension through fluctuations in climate or moisture content. Differences in this property between plywoods would not be significant.

Weathering: Weathering involves a change in color, roughening and checking of the surface, and cupping and tearing loose from the fastenings. This does not include decay. Comparisons were made from table on page 43 of the Wood Handbook.

Paintability: classification is based on how well a material will take the paint and how often repainting is required. Only exterior painting was considered. Comparisons were made from table on page 358 of the Wood Handbook. Also includes staining properties.

Gluability: refers to the ability of wood to be glued to other products and to itself during manufacture. Comparisons made from a table on page 358 of the Wood Handbook.

Appearance: refers to the visual characteristics of the plywood panel. In some cases the appearance may play an important role in the final use of the plywood. The appearance of the different plywoods varies considerably and any rating of appearance would be very subjective.

Acoustical Insulation: the ability of the material to restrict sound from passing through it. It was thought that any differences between plywoods would be too small to measure.